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METALS & ALLOYS

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The Magazine of Metallurgical Engineering

INCLUDING

CURRENT METALLURGICAL ABSTRACTS

THE OLYMPIAN on lower track, showing switch backs in Bitter Root Mountains. (*Courtesy Chicago, Milwaukee, St. Paul and Pacific R. R.*)

VOLUME 3

NUMBER 6

JUNE 1932

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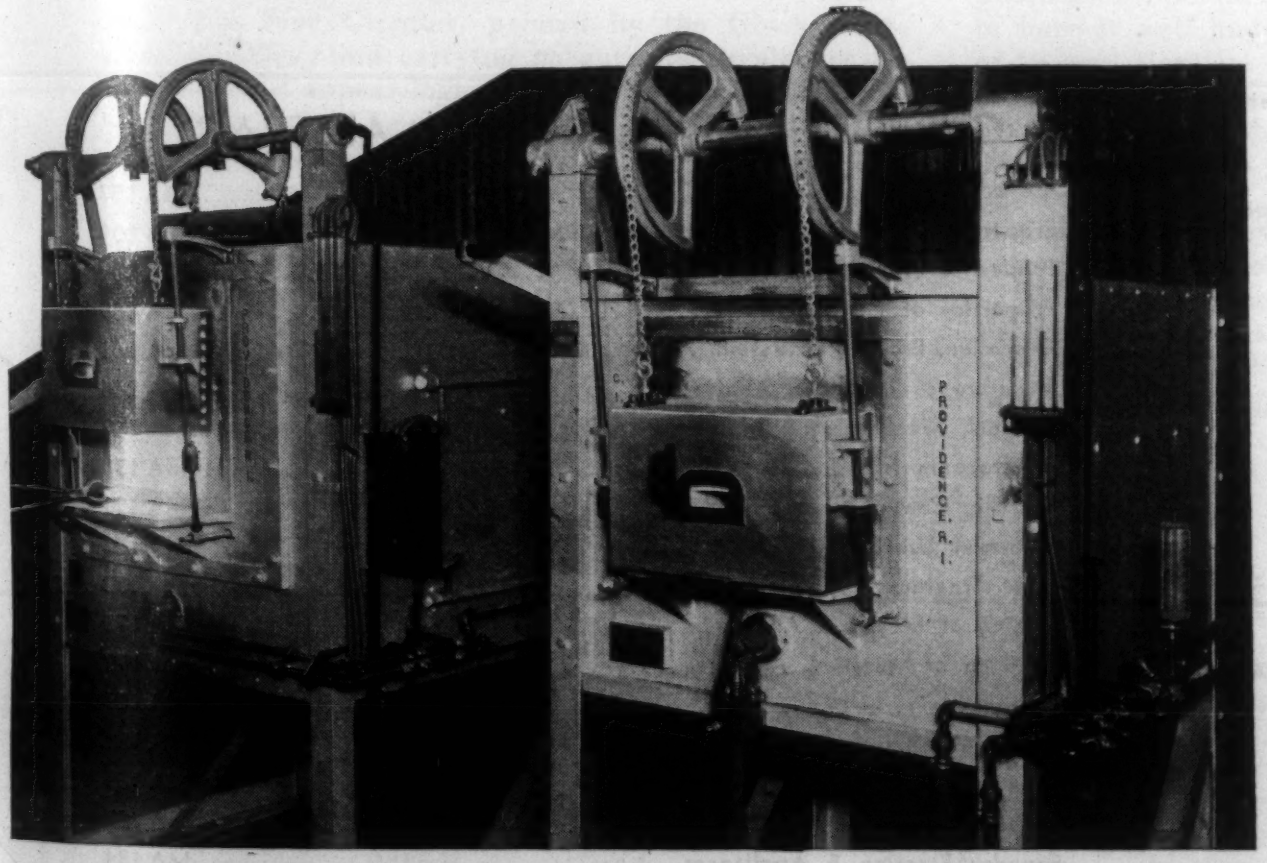

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EDITORIAL COMMENT

Written Discussion

IN AN anonymous review of the recently-published Bureau of Standards Circular on "Zinc and its Alloys," the *Metallurgist* discusses the propriety of a Government laboratory publishing "ex cathedra" statements, backed by the weight of Government authority, in pamphlets of this sort rather than through the channels of technical societies where discussion is courted. The particular occasion for the comment seems to be that British toes are stepped upon by the statement that there is no allotropy in pure zinc. Since the British long insisted, from work on impure zinc, that allotropy did exist, they seem unwilling to admit that they were wrong and the reviewer argues that the pure metal might want to undergo an allotropic change but is only able to do so in the presence of impurities!

The National Physical Laboratory is patted on the back for presenting its findings before technical societies so that those who don't agree may indulge in free criticism. There is something in this, for we recall one such N.P.L. publication on nickel steel where the discussion did vastly illuminate the paper.

Nevertheless, N.P.L. work is often published in Aeronautical Research Reports that do not admit discussion, and such books by N.P.L. workers as those of Tapsell on Creep of Metals and Gough on Fatigue of Metals are in the same category as the Zinc Circular as far as discussion goes.

One difference is that Tapsell's book costs $12.00, while the Zinc Circular, printed by the Government Printing Office, and carrying no author's royalty, costs 70c. It would appear logical that work done on Government funds should be published in such fashion that private gain is eliminated.

The finances of technical societies in England may be such that they could publish a 214 page book such as the Zinc Circular, and present it at a technical meeting for discussion, but it would certainly be difficult to do that here. As a matter of fact, technical sessions are so crowded nowadays that seldom is adequate oral discussion possible, and about all that is usually gained is an opportunity to file written discussion for later publication.

The *Metallurgist,* by bringing up the point of view that its reviewer holds on allotropy, appears to answer its own question, for there is no reason why material published in a book, a circular, or in a journal that does not admit discussion, cannot be discussed elsewhere, e.g., in the *Metallurgist.*

The question raised does not appear to us very important in the case of publications of the nature of the Bureau of Standards Circulars. It might apply with more force to the papers published in the *Bureau of Standards Journal of Research.* In the past there has been much duplicate publication, an article appearing as a Scientific or Technological paper, or in the *Journal of Research,* being reprinted verbatim, or in re-hash, in the transactions of some technical society, in which case discussion can be had, but the need for economy in printing costs in the face of a rising tide of technical papers deserving of publication will soon practically eliminate such duplication by technical societies. The Bureau might split its publications two ways, the papers fitting into the fields of technical societies, going there, and the others appearing in the *Journal of Research,* but so long as sufficient Government funds are available for printing it all in the *Journal of Research,* the desire to have all its work appear in its own journal will probably make the Bureau perpetuate the condition criticized by the *Metallurgist.*

There is one real advantage in this for the reader who may wish to locate some publication of the Bureau, in that, with it all in the *Journal of Research,* he need look in but one place.

There are three ways in which the difficulty may be partly or wholly overcome. The articles could be mimeographed and distributed for comment and criticism to those most competent to make comment, and the comments utilized in making the final draft for publication. *Metals & Alloys* often uses this method in the preparation of its own Correlated Abstracts, and we believe it worthy of wider adoption.

Or, the *Journal of Research* could open its columns to discussion of papers previously printed therein. But, being a Government publication, it would have difficulty in declining to print a windy discussion by someone with an axe to grind, for that person's Congressman would immediately be inquiring why his constituent's discussion was censored out.

The third alternative, applying not merely to Bureau publications, but to technical publications in general, is to have it well understood that constructive discussion of papers, circulars and books for which other avenues of discussion are not provided, may be had in the columns of journals that deal with the subjects at issue. The editors of such journals can cast out the axe-grinding discussions and those of the polemic type, but can perform a service by publishing valuable data and comment that amplify or correct the material on record.

With the understanding that its editorial staff will be the judge as to what of the discussion offered is pertinent and valuable, *Metals & Alloys* offers its columns for constructive discussion of metallurgical publications.—H. W. GILLETT

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Good Discussions

IN LINE with our editorial policy of commenting now and then on good sessions, good presentation of papers and good discussion at technical society meetings, we mention the Gray Iron Session at the American Foundrymen's Association meeting in Detroit, May 4.

The five papers on the program were too many for the two hours of a session that started a bit late, especially since the long Institute of British Foundrymen and French Technical Foundry Association exchange papers were among the five, and since only one or two papers had come in in time to be preprinted. Hence, rather lengthy abstracts had to be given and some of the presentations were so detailed that nobody felt like taking up more time in discussion. The Chairman, Hy Bornstein, handled the session well in spite of these handi-

caps, and had the satisfaction of having one paper on the program that elicited good old-fashioned discussion.

This was the paper on High Test Iron, by H. H. Judson, of Gould's Pumps, Inc. Judson didn't read his paper, but summarized its contents in concise fashion, and got all his points across nicely.

His statements that melting steel scrap in one cupola, soft iron in another and mixing the two in the ladle, produced high test iron that pulled some 50,000 lbs./in.^{2}, in specimens cut from big castings, no section of which was under 2½ inches thick, and that the castings did not require larger gates or larger risers than soft iron, as one would normally expect in the case of low-carbon high test iron, were listened to with real interest. He believes that there is a difference in metal so produced from that of the same chemical analysis produced in one melt. He offered no theory for the difference but invited suggestions of a theory. That he found it necessary to take the steel melt from the cupola as soon as possible, and to pour the mixed iron without much delay in order to get the good results, was taken by some who discussed the paper, as an indication that gases might be responsible for shrinkage and other difficulties, in other melting practices.

The discussion was of an unusually high order. It was a particular pleasure to listen to the clearly phrased comments of Dr. Fritz Meyer. On the whole, the discussers did not appear to doubt the facts so forcefully presented by Mr. Judson, but they did doubt their own ability to produce the results reported by him, without duplicating his practice.

Unless we miss our guess, a good many foundrymen will go back home and try the two-melt scheme. A paper and a discussion that thus arouses, not merely talk, but action also, certainly deserves our mention.

Judson's comment that little separately cast test bars "told lies" about the big castings he was making, so that he had to take specimens from the castings themselves, would, had time permitted, have brought on further interesting discussion.—H. W. GILLETT

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Service Testing of Automotive Products and Correlation with Laboratory Tests

Seven prominent executives and engineers discussed various aspects of Service Testing of Automotive Products and Correlation with Laboratory Tests at a joint meeting in Detroit on Monday evening, March 28, under the auspices of the A.S.T.M. Detroit District Committee and the Detroit Chapters of the A.S.S.T. and the S.A.E. The various aspects of service testing of automotive products and the correlation with laboratory tests were discussed. The titles of the papers were:

Introduction. F. O. Clements, Technical Director, Research Laboratories, General Motors Corp.

Road Testing of the Entire Automobile. A. J. Schamehorn, Director, General Motors Proving Ground.

Destructive Testing of Automotive Products. J. M. Watson, Metallurgical Engineer, Hupp Motor Car Corp.

Service Complaints on Automobiles as Related to Engineering Tests. Nicholas Dreystadt, General Service Manager, Cadillac Motor Car Company.

Relation of Service Testing to Metallurgy of Automobile Parts. J. L. McCloud, Metallurgist, Ford Motor Company.

Service Tests of Automobile Fuels and Lubricants. D. P. Barnard, Research Engineer, Standard Oil Company (Indiana).

Service Testing of Automobile Tires. S. M. Cadwell, in charge of Tire Development, U. S. Rubber Company.

Committee of A. S. T. M. Studying X-ray Testing Methods

A subcommittee of A.S.T.M. Committee E-4 on Metallography is actively engaged in investigative work in the X-ray and gamma ray testing field. This group of men, comprising Subcommittee VI on X-ray Methods, has been considerably enlarged. Four experts on the subject have been added as new members and invitations will be extended to others to cooperate in the work.

Gamma ray testing and other non-destructive tests have been the subject of much recent discussion among members of the Society, and it is assured that the Subcommittee on X-ray Methods will be well qualified to undertake the solutions of testing problems in this field. L. W. McKeehan, Professor of Physics, Yale University and chairman of this committee, reports progress, particularly in better equipment, pointing out that the latest work on improved methods has been done abroad. Literature and data on the subject are available to members of the subcommittee.

Certain power cable interests have become greatly interested in the examination of lead and lead alloy cable sheaths. With this in view, and because of the dearth of concise information, there has been prepared a technical report, with comments by several members of Committee E-4, on the subject of Metallographic Methods for the Examination of Lead and Lead Alloys. Since this promises to be of great value to the power cable industry and to all users of lead sheath cable, it is planned to publish, at the time of the next A.S.T.M. annual meeting, a technical paper on the subject. A recommended practice will be included with the present revision of the Recommended Practice for the Examination of Non-Ferrous Alloys.

Subcommittee I of E-4 on Selection and Preparation of Samples, Mr. E. H. Dix, Jr., Metallurgist, Aluminum Research Laboratories, Chairman, is actively engaged in reviewing the present Standard Methods of Metallographic Testing of Iron and Steel (E 3-24) and the Standard Methods of Metallographic Testing of Non-Ferrous Metals and Alloys (E 5-27).

Subcommittee IV on Photography, Mr. H. S. Rawdon, Chief, Division of Metallurgy, U. S. Bureau of Standards, Chairman, is at work on the problem of selecting proper combinations of objectives and oculars for various magnifications. Both of these committees and the Special Committee on Grain Characteristics of Steel are planning full sessions at the time of the Spring Group Meetings in Cleveland, March 7-11.

C. H. Davis, Assistant Metallurgist, American Brass Company, Chairman and O. E. Harder, Assistant Director, Battelle Memorial Institute, Secretary, are directing the activities of Committee E-4.

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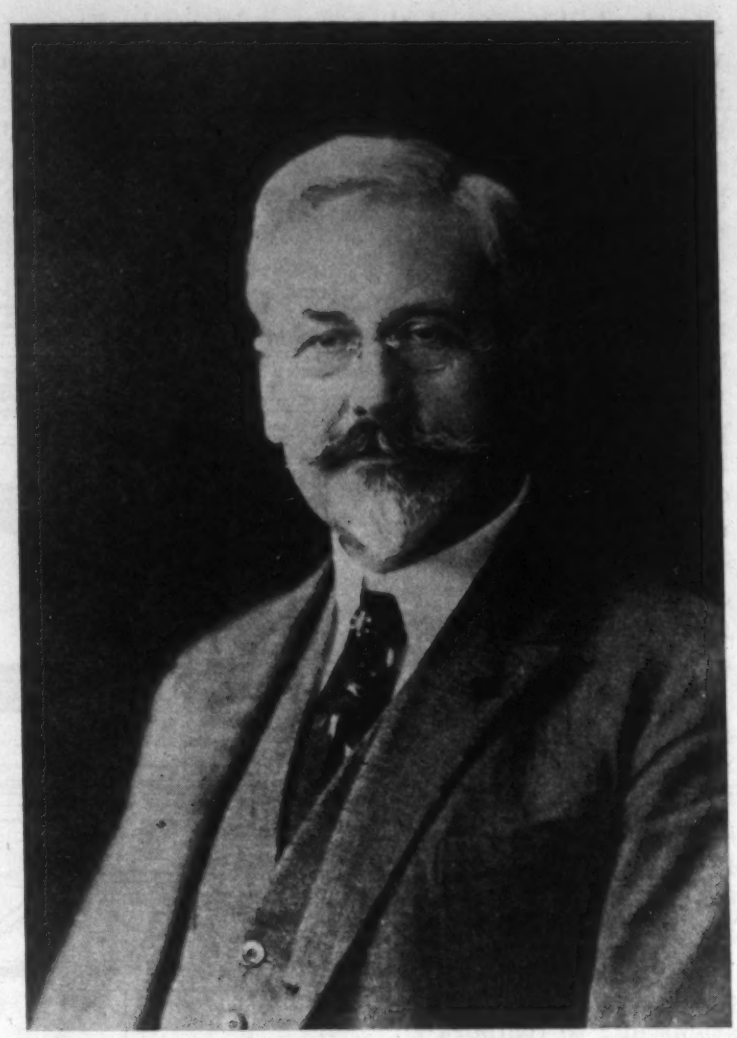
According to a recent research report by Dr. A. W. Coffman, a new protected metal called "Robertson-Bonded Metal" has been carried through the laboratory stages of development at Mellon Institute of Industrial Research.

Robertson-Bonded Metal is the result of extensive research that has led to the production of a laminated metal-felt material in which felted materials are cemented to steel with heat and pressure, utilizing metals as adhesives. The composite laminated material, the outer surfaces of which are suitable felts, is then saturated with any desired saturant chosen with reference to the corrosive condition to which the metal is to be exposed in service. Paint, lacquer and resin films superimposed on the saturated felt give not only added protection but also desired attractiveness of appearance in the finished product. Owing to the fact that it is possible to choose between a number of felts and felt saturants to stand against various corrosive conditions, this new protected metal promises flexibility in providing corrosion resistance. The ductile nature of the metal bond between felt and steel makes it possible to subject this material to forming operations such as shearing, bending, corrugating, rolling and mild drawing without destroying adhesion between felt and steel. By selecting asbestos felt together with fireproof saturant a fireproof material results, while an increased insulating value over that of bare metal is obtained with any combination of felt and saturants. It is also claimed that this new material of construction has the strength of metal with none of the attendant "ring" and reverberation of bare metal.

INVAR, ELINVAR and Related Iron-Nickel Alloys†

By J. W. SANDS*



Dr. Charles E. Guillaume, developer of the alloys "Invar" and "Elinvar."

ALLOYS WITH LOW OR SPECIFIC EXPANSION PROPERTIES

SINCE the discovery by Guillaume[1] in 1898 of the inherent low expansivity at ordinary temperatures of certain iron-nickel alloys, the expansion characteristics of the iron-nickel system throughout the entire range of nickel contents have been very fully investigated. As a result of these labors there is now available to the engineer in certain of the ferro-nickels, not only an alloy possessing a negligible coefficient of expansion at atmospheric temperatures but also alloys with any desired degree of expansivity between zero and that of nickel. Apart from unusual expansion properties, the value of this class of materials from an engineering standpoint is enhanced by high strength and ductility, great toughness, high electrical resistance, and relative incorrodibility.

Due, perhaps, to the fact that they were discovered in France and subsequently developed mainly in that country, these steels do not seem to have been accorded in America the recognition as an important and useful class of engineering materials to which their unique combination of properties would seem to entitle them. Possibly this condition is due to lack of a brief but comprehensive source of specific data upon the expansion and other properties of these alloys. It is in an endeavor to remedy such a deficiency that the present compilation has been made.

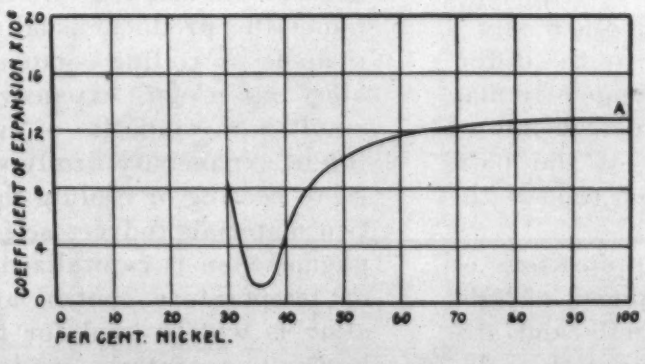


Fig. 1. Coefficients of linear expansion per °C. at 20°C. of typical nickel-iron alloys containing 0.4% manganese and 0.1% carbon. (Guillaume.)

Variation of Expansion With Nickel Content

When the coefficient of linear expansion at room temperature of the iron-nickel alloys is plotted against nickel content, the resulting curve has the form shown in Fig. 1. The composition corresponding to the deep minimum in the vicinity of 36% nickel was found by Guillaume to maintain its dimensions so nearly constant when subjected to ordinary variations of atmospheric temperature that he bestowed upon it the appropriate name of "Invar."

As the nickel content of the alloys is increased from the Invar point, the expansion coefficient increases continuously, but not uniformly, until it reaches at A the value corresponding to 100% nickel. By special processing the Invar minimum shown in Fig. 1 may be further depressed until it is tangent to the zero axis; so it is evident that there is available in the iron-nickel alloys any desired coefficient of expansion between 0 and 13 $\times$ 10^{-6} per °C. (7.2 $\times$ 10^{-6} per °F.) which is the value corresponding to pure nickel. The alloys with less than about 30% nickel cannot be considered in this connection as they are unstable (see later section "Constitution of Iron-Nickel Alloys"), but are, as will be shown later, of considerable value for applications requiring a strong, tough, corrosion resistant non-magnetic material.

Some Applications of the Alloy of Minimum Expansivity (Invar)

The 36% nickel alloy, Invar, is principally valuable because of its extremely low expansivity, although its relative incorrodibility, high strength and great toughness contribute to its usefulness. It is used for length measures, such as tapes for geodetic measurements, and has been found highly satisfactory for this service as measurements may be made in daylight with very small corrections for temperature. The Bureau of

*Research Laboratory, Development and Research Department, The International Nickel Company, Inc., Bayonne, N. J.

†First Part of this Paper. The second part will appear in the July issue.

Standards has found that properly made Invar tapes will vary less than one part in 500,000 after six months' use in the field. Length measures of Invar wire are also used to some extent, although wires are subject to errors due to twist which are not present in tapes. Invar is particularly well adapted for length standards, such as standard meter bars.

Invar is used for numerous instruments requiring fixed distances between points which must be independent of temperature. The ease with which minute lines may be ruled on polished Invar surfaces contributes to its usefulness for measuring devices.

The development of Invar, and related nickel steels, has profoundly influenced the art of horology. The use of these alloys in timepieces has greatly increased their accuracy due to the practical elimination of variations due to temperature. Invar, or similar metals, have displaced mercury in compensated clock pendulums, resulting in simplification of design and increased accuracy. Clocks with compensating torsion pendulums of nickel steel require very little driving power, and may be constructed to run for as many as 400 days on a single winding.

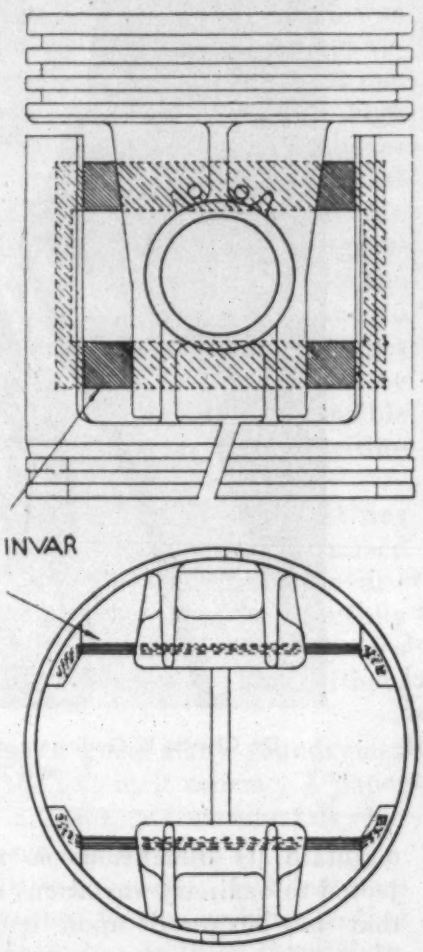


Fig. 2. Construction of the "Hollow Square" Type of Aluminum Alloy Piston.

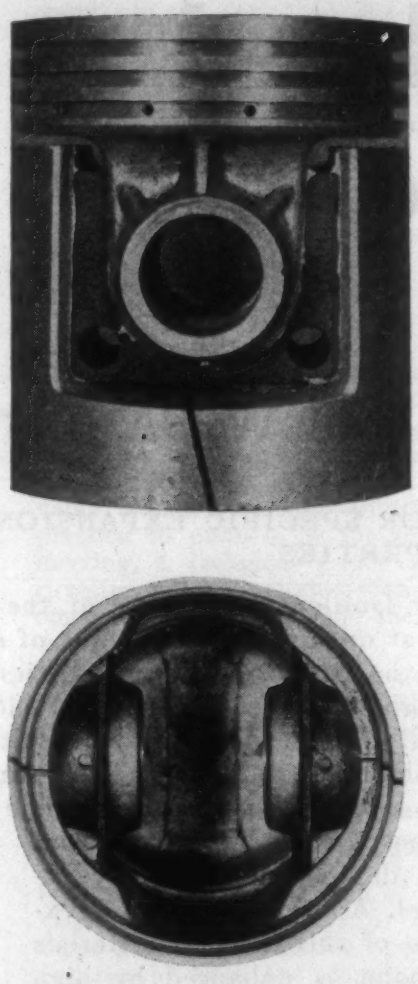


Fig. 3. Aluminum alloy piston with Invar struts.

An important, and rapidly growing use of Invar is in connection with expansion control in cases where two machinery parts of different coefficients of expansion must work in close conjunction with each other over a temperature range. Any difficulties caused by the different rates of expansion of the two parts frequently may be overcome by the introduction of the proper amount of Invar into the more expansible member of the pair, whereby its expansion is cut down to match that of the other.

One of the most widely known Invar applications of this type was made necessary by the development of light aluminum alloy pistons for use in automobile and airplane internal combustion engines. Because of the relatively high expansion of aluminum as compared with cast iron, it was necessary when using uncompensated pistons to allow a large clearance between piston and cylinder wall in order to eliminate any danger of seizing at the higher operating temperatures. Engines so equipped were unsatisfactory due to piston slap, high rate of cylinder wear and excessive oil pumping.

Some improvement was obtained by the use of pistons of special design with slots and grooves located at strategic points, but the problem was not completely solved until the introduction of Invar into the construction of the piston.[2] One method of using Invar has been developed by the Bohn Aluminum and Brass Corporation. A piston of the split skirt type is used with Invar struts cast in across the piston in such a manner that lateral expansion with increasing temperature is held down to a rate commensurate with that of the cylinder block.

Another method of using Invar is in what is known as the "hollow square" type piston. This has been developed by E. T. White and Company (1926) Limited of London. The location of the Invar "squares" in the piston is illustrated in Fig. 2. In some pistons of this type there is no connection between the piston head and the piston skirt, except through the Invar struts (Fig. 3), but somewhat greater rigidity without sacrifice of any of the benefits conferred by the Invar struts is obtained by connecting the piston pin bosses with the lower and cooler portions of the piston skirt as indicated in Fig. 2. With Invar strut pistons of either type, very small clearances between piston and cylinder wall are permissible. As low as 0.003 inch with a 4 inch diameter piston is said to be feasible.

The Invar used in aluminum piston construction is not usually of the composition offering minimum expansion. A nickel content of 32 to 34% has been found to offer the best properties for this particular service.

A large amount of Invar and related nickel steels is used in the manufacture of thermostatic metal. This is a bimetallic product, usually in the form of strip, which is made by rolling compound bars of the low expansion alloy and a more expansive material, usually brass. The result is a composite of two metallic strips of quite different expansivity firmly welded together. When subjected to heating or cooling the differential expansion of the two materials induces self-bending of the strip and this phenomenon is capitalized to advantage for a multitude of temperature control applications. The 42% nickel alloy is widely used for this purpose, especially where higher temperatures are involved.

Some Applications of the Alloys of Specific Expansion Properties

Steel with 42% nickel, despite its higher coefficient of expansion, is sometimes used for length standards in place of Invar because of its greater dimensional stability. It is less subject to the transitory and permanent length changes discussed below in the case of Invar, and its property of low expansivity persists to a higher temperature than is the case with Invar. The use of this steel for metallic arc welding has recently been patented.[3] In this application the low expansion coefficient

of the alloy is said to be responsible for a decrease in the shrinkage of the weld on cooling with a consequent marked amelioration of internal strains.

Steel with 46% nickel is called "Platinite" because of the fact that its coefficient of expansion is almost the same as that of platinum; that is to say, about 9×10^{-6} per °C. (5×10^{-6} per °F.). It was formerly used in place of platinum for sealing in leads in electric light bulbs and radio tubes, but it has since been replaced by a duplex wire known as "Dumet," which has been found to be more suitable. Dumet consists of Platinite wire with an oxidized copper plated coating which, when properly processed, makes a very strong bond with the glass. The copper coating, which may constitute 20% of the cross-sectional area, also provides good electrical conductivity, a property in which Platinite is somewhat deficient. Among other metal to glass applications Dumet is being used to seal the leads into hermetically sealed electric refrigerator mechanisms.

For use in connection with low expansion glass throughout the temperature range 0° to 450°C. (32° to 842°F.) the 39% nickel alloy provides the proper expansivity. This alloy is of value in the construction of radio power tubes which are frequently made from such special glass.

The 56% nickel-iron alloy has about the same coefficient of expansion as ordinary steel (about 11×10^{-6} per °C. or 6×10^{-6} per °F.), and this fact makes it useful for industrial measuring machines used for testing the dimensions of steel gages and machine parts. Such machines constructed of this alloy are very stable, highly resistant to corrosion, and make temperature corrections unnecessary.

Two other commercially produced alloys which take advantage of the flexible expansion properties of the iron-nickel system are known as "Dilver" and "Adr."

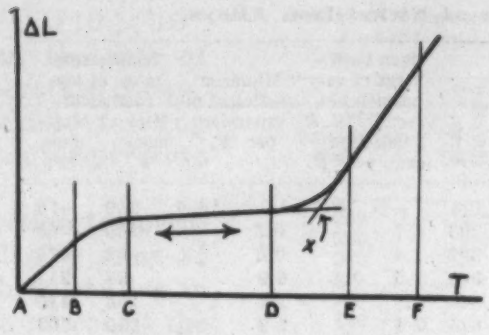


Fig. 4. Change in length (ΔL) with temperature (T) of a typical low-expansion iron-nickel alloy. (Guillaume.)

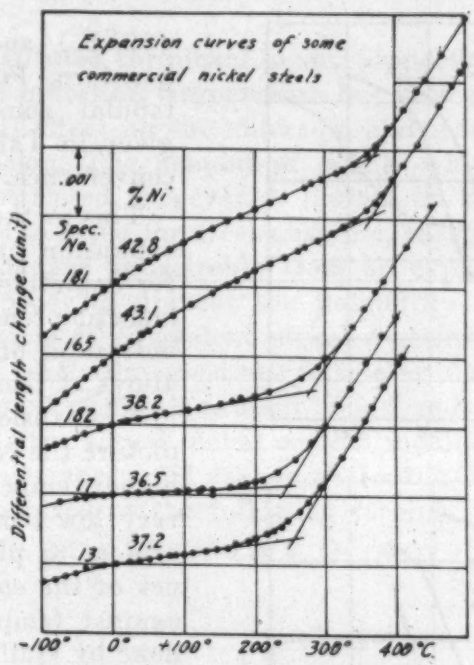


Fig. 5. Expansion curves of some commercial low-expansion nickel steels. (Scott.)

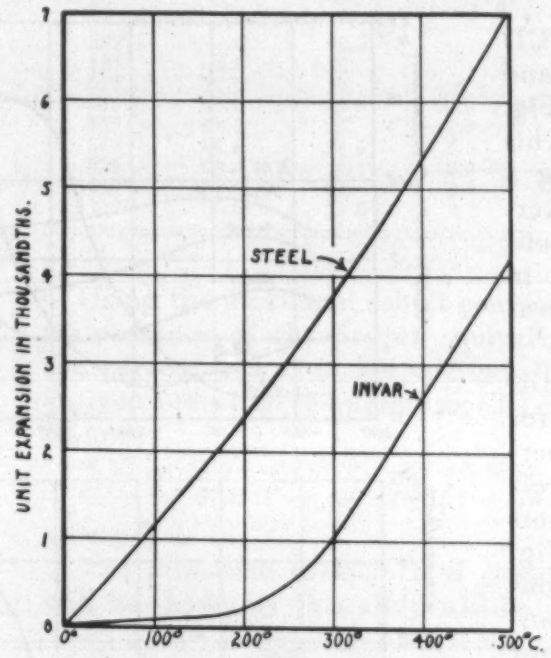


Fig. 6. Expansion curves of Invar and ordinary carbon steel. Invar curve according to Scott. Carbon steel curve according to Souder and Hidnert.[5]

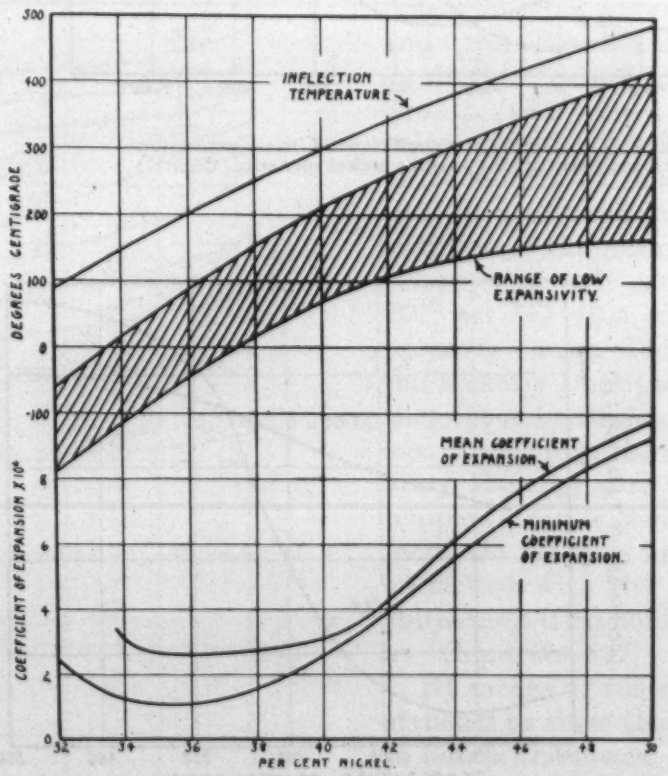


Fig. 7. Effect of nickel content on the expansion characteristics of iron-nickel alloys. (Scott.)

Dilver has an expansion coefficient nearly the same as ordinary glass (about 8×10^{-6} per °C.; 4.5×10^{-6} per °F.). Adr has a total expansion between 0° and 500°C. (32° and 932°F.), which is less than that of any ordinary metal. The trade-marks "Invar," "Elinvar," "Dilver," "Adr," and "Platinite," are owned by the Societe Anonyme de Commentry-Fourchambault et Decazeville of Paris, France.

Effect of Temperature Upon the Expansivity of the Iron-Nickel-Alloys

In applying the low expansion nickel steels to individual applications it must be recognized that the low expansion characteristics of these alloys are only available over a limited temperature range. The general shape of an expansion-temperature curve of a typical alloy of this group is shown in Fig. 4. Starting at a very low temperature A, the length increases moderately and fairly uniformly until the Point B is reached. In the interval between B and C the rate of expansion decreases markedly until a more or less constant low rate is attained which endures throughout the range CD. At D the length begins to increase more rapidly until at E the expansion rate has become quite high. The interval CD corresponds to the range of lowest expansivity and therefore to the most useful temperature range of the alloy. The width and location of the region CD as well as the slope of the curve between these points (and consequently the value of the minimum coefficient of expansion) will vary with the composition and previous history of the alloy.

The temperature range DE is important in that it marks the upper temperature limit of the range of low expansivity of the steel in question. For the sake of brevity, in the discussion which follows this region will be referred to by a single temperature designated as the "inflection temperature." This is the temperature fixed by the intersection of the slopes of the

Table 1. Expansion Properties of Nickel-Iron Alloys.

Nickel content %	Inflection Temp. °C.	Mean Coefficient of expansion between 0°C. & inflection temp. per °C.	Minimum coefficient of expansion per °C.	Temperature range of low coefficient Minimum °C.	Temperature range of low coefficient Maximum °C.	Nickel content %	Inflection Temp. °F.	Mean Coefficient of expansion between 32°F. & inflection temp. per °F.	Minimum coefficient of expansion per °F.	Temperature range of low coefficient Minimum °F.	Temperature range of low coefficient Maximum °F.
32	90	– × 10–6	2.4 × 10–6	–190	–60	32	194	– × 10–6	1.3 × 10–6	–310	–76
34	145	3.1	1.2	–110	20	34	293	1.7	0.7	–166	68
36	200	2.6	1.1	–45	90	36	392	1.4	0.6	–58	176
38	250	2.7	1.6	20	155	38	500	1.5	0.9	68	311
40	300	3.1	2.5	70	210	40	572	1.7	1.4	158	410
42	340	4.3	3.9	110	265	42	644	2.4	2.2	230	509
44	380	6.1	5.6	135	310	44	716	3.4	3.1	266	590
46	420	7.7	7.0	150	350	46	788	4.3	3.9	302	662
48	455	8.9	8.4	160	385	48	851	5.0	4.7	320	725
50	490	9.8	9.3	165	420	50	914	5.5	5.2	329	788

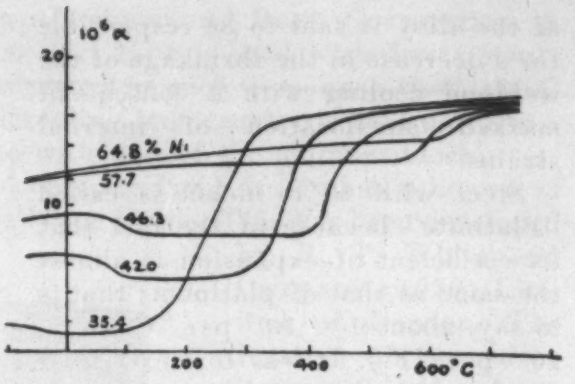


Fig. 8. Variation of the coefficient of linear expansion (α) with temperature for various nickel contents. (Guillaume.)

curve in the regions CD and FE of Fig. 4, and is represented in Fig. 4 by the point X. This method of choosing a temperature characteristic of the continuous expansion change in the region DE was originated by Scott.[4]

Actual expansion-temperature curves for a number of commercial high nickel steels as determined by Scott are reproduced in Fig. 5. These steels contained about 1% manganese and around 0.1% carbon. The curves are fairly representative of what may be expected of regular commercial production in the natural or annealed condition. The difference in the manner of expansion between these steels and ordinary carbon steel is brought out in Fig. 6 in which the expansion-temperature curves of Invar and ordinary carbon steel are plotted on the same chart.

From a similar, but more complete series of curves than is shown in Fig. 5 data may be taken which will show very clearly the effect of varying nickel content upon the expansion characteristics of the low expansion alloys. One method of picturing such data graphically is shown in Fig. 7. Throughout the temperature range indicated by the shaded area in this figure the expansion is very nearly a straight line corresponding to the minimum coefficient of expansion. In this region the expansion coefficient does not change more than 0.5×10^{-6} per °C. (0.3×10^{-6} per °F.). The curve of the mean coefficient of expansion holds between 0°C. (32°F.) and the inflection temperature. For some purposes the tabular summation of this data given in Table 1 may be of more convenience.

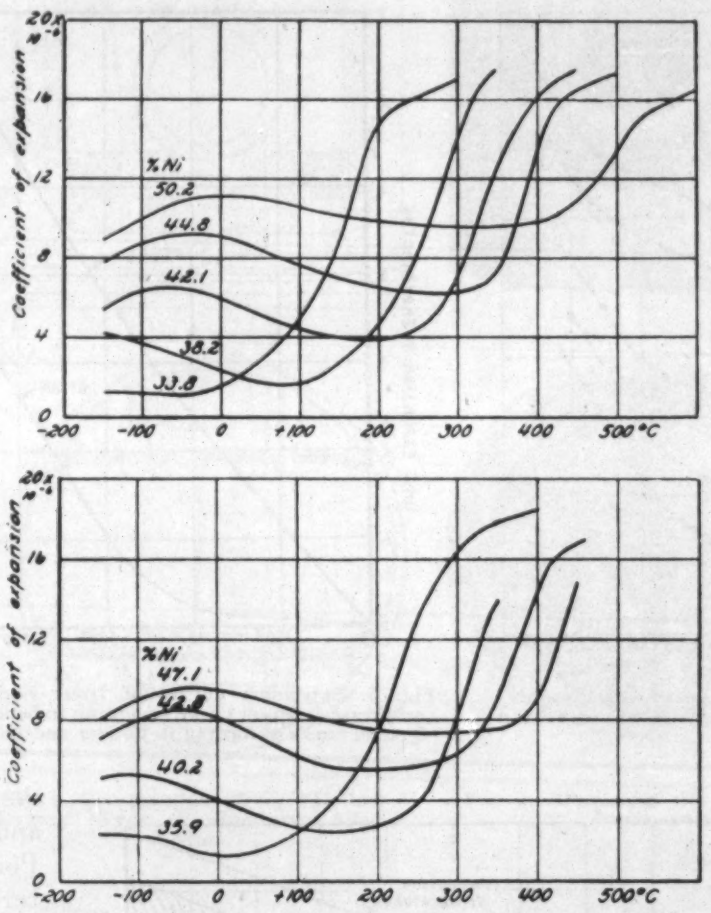


Fig. 9. Variation of the coefficient of linear expansion with temperature for various nickel contents. (Scott.)

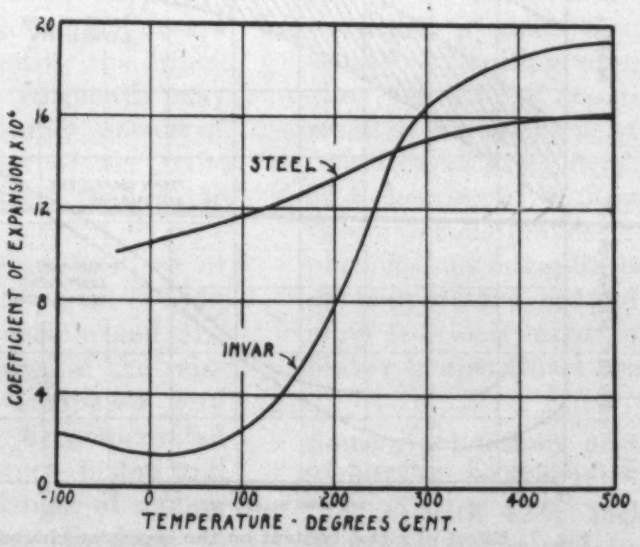


Fig. 10. Variation of the coefficient of linear expansion with temperature for Invar (Scott) and ordinary carbon steel. (Souder and Hidnert.)

This method of representing the expansion properties is admirable for depicting conditions below the inflection temperature but gives no indication of the behavior of the alloys at temperatures outside the low expansion range. In order to picture the conditions obtaining at higher temperatures (as well as at very low temperatures) it is convenient to plot instantaneous values of the coefficient of expansion against temperature as has been done by Guillaume in Fig. 8. The more recent determinations of Scott are shown in the same manner in Fig. 9. A comparison of Scott's results on the Invar composition with those of Souder and Hidnert for ordinary carbon steel is given in Fig. 10.

Another method of coördinating coefficient of expansion, temperature and composition on a single chart is shown in Fig. 11, according to Chevenard. One of the interesting points of this figure is the indication that the alloy containing slightly greater than 50% nickel possesses a practically constant coefficient of expansion between 0° and 400°C. (32° and 752°F.)

The charts comprising Fig. 1 and Figs. 4 to 11 give a comprehensive view of the relations between expansivity, temperature and composition existing in the range 30 to 60% nickel. Summed up briefly, they show that the upper temperature limit of low expansivity (inflection temperature) may be raised by increase in nickel content but only at the expense of an increase in the minimum and mean expansion rates. Above the inflection temperature the rate of expansion of all the steels becomes

almost the same at about 18×10^{-6} per °C. (10×10^{-6} per °F.) which is somewhat higher than the rate of ordinary carbon steel in the same temperature range. Thus the degree of low expansion available for any application is dependent upon the maximum temperature at which the alloy is to be used.

The utility of the alloys of higher inflection temperature may be somewhat increased by replacing some of the nickel with cobalt, an element which is similar in many ways to nickel. By such substitution of cobalt the expansivity for a given inflection temperature may be reduced, or conversely a given expansivity may be made available over a wider temperature range. The effect of cobalt additions has recently been studied very thoroughly by Scott[6] whose work forms the basis for the following discussion.

Cobalt may be substituted for nickel in any proportion without effect on the inflection temperature but with an increasingly beneficial effect on the minimum and mean coefficients of expansion. The amount of cobalt which may be safely so substituted, however, is limited by the fact that cobalt tends to make the steel unstable, that is, to introduce phase changes undesirable from an expansion standpoint. In order to prevent the possibility of such instability the ratio of equivalent nickel content to iron content in % of total alloy must not fall below 0.55 regardless of the amount of cobalt present. The "equivalent" nickel content is the actual nickel content modified by the effect of the manganese and carbon present in the alloy and may be expressed by the following formula:

$$\text{Equivalent \% Ni} = \%\ \text{Ni} + 2.5\ (\%\text{Mn}) + 18\ (\%\text{C}) \quad (1)$$

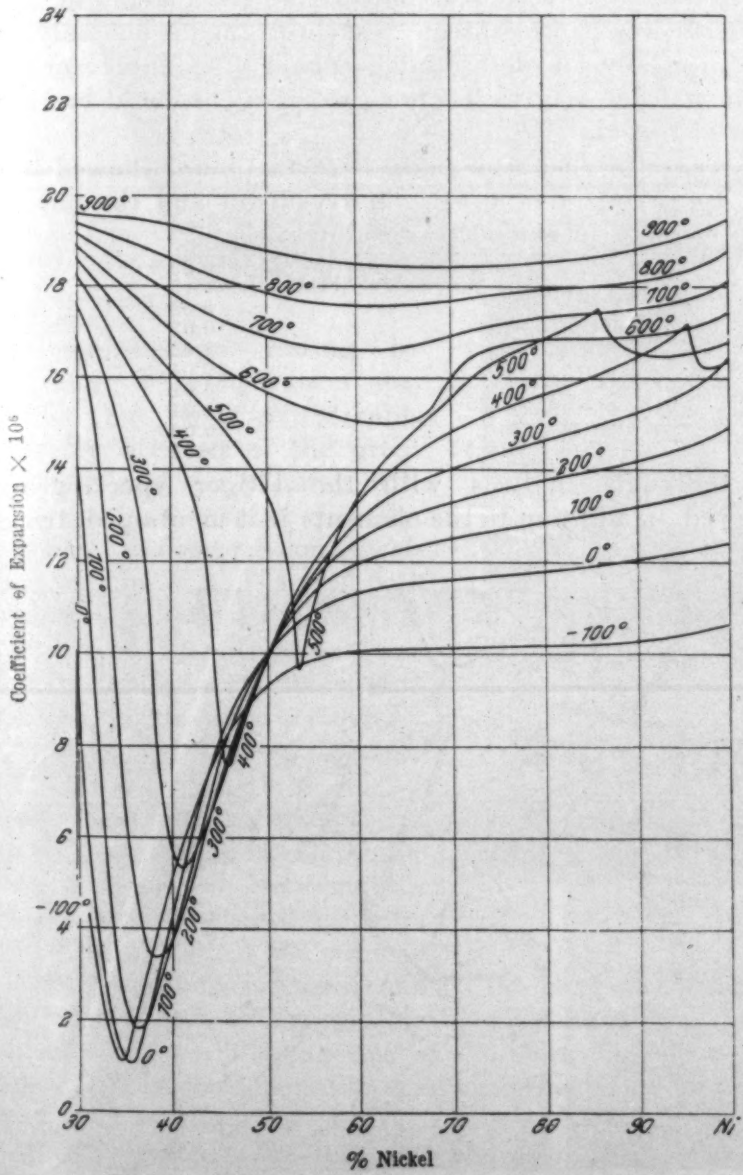


Fig. 11. Variation of the coefficient of linear expansion with nickel content at various temperatures. (Chevenard.)

Table 2. Expansion Properties of Alloys Containing Optimum Cobalt and Nickel Contents in the Presence of 0.5% Manganese and 0.2% Carbon.

Inflection Temp. °C.	Cobalt %	Nickel %	Minimum coefficient of expansion per °C.	Mean coefficient of expansion per °C. between 0°C. and inflection temp.
200	4.0	30.5		
250	8.0	29.		
300	12.0	28.		
350	16.0	26.5	1.7×10^{-6}	2.8×10^{-6}
400	20.0	25.	2.9	4.0
450	24.0	23.5	4.1	5.2
500	28.0	22.	5.3	6.4
550	32.0	21.	6.5	7.6
600	36.0	19.5	7.7	8.8

Inflection Temp. °F.	Cobalt %	Nickel %	Minimum coefficient of expansion per °F.	Mean coefficient of expansion per °F. between 32°F. and the inflection temp.
392	4.0	30.5		
482	8.0	29.		
572	12.0	28.		
662	16.0	26.5	0.9×10^{-6}	1.5×10^{-6}
752	20.0	25.	1.6	2.2
842	24.0	23.5	2.3	2.9
932	28.0	22.	2.9	3.5
1022	32.0	21.	3.6	4.2
1112	36.0	19.5	4.3	4.9

Using the maximum cobalt content consistent with the maintenance of the proper equivalent nickel-iron ratio, the percentages of nickel and cobalt necessary to obtain a given inflection temperature (T) may be calculated as follows:

$$\%\text{Ni} = 41.9 - .0282\ \text{T} - 3.7\ (\%\text{Mn}) - 19\ (\%\text{C}) \quad (2)$$

$$\%\text{Co} = .0795\ \text{T} + 4.8\ (\%\text{Mn}) + 19\ (\%\text{C}) - 18.1 \quad (3)$$

where T is in °C.

The minimum coefficient of expansion per °C. which will be shown by this alloy will be

$$\alpha_1 \times 10^6 = .024\ \text{T} + 0.38\ (\%\text{Mn}) - 1.2\ (\%\text{C}) - 6.65 \quad (4)$$

and the mean coefficient of expansion per °C. between 0°C. and the inflection temperature will be

$$\alpha_2 \times 10^6 = .024\ \text{T} + 0.38\ (\%\text{Mn}) - 1.2\ (\%\text{C}) - 5.6 \quad (5)$$

The formulae for nickel and cobalt contents hold for inflection temperatures between 200° and 600 °C. (392° and 1112°F.), but the formulae for α_1 and α_2 are only applicable for inflection temperatures between 350° and 600°C. (662° and 1112°F.). For inflection temperatures below 350°C. (662°F.) the expansion coefficient cannot be so simply calculated although the improvement persists in a less marked degree. Scott states that the substitution of the permissible amount of cobalt in the Invar composition will reduce the expansion by about 0.5×10^{-6} per °C. (0.3×10^{-6} per °F.) in the ordinary temperature range. This statement has been confirmed by the recently published paper of Masumoto,[7] who reports that the substitution of 5% cobalt for the same percentage of nickel in the ordinary Invar composition yields an alloy showing zero coefficient of expansion at ordinary temperatures without special processing or heat treatment. So far as is known it is impossible to secure a zero coefficient with the ordinary Invar composition without subjecting it to cold work. Masumoto refers to his alloy as "Super-Invar."

By means of the above formulae Table 2 has been constructed to show the nickel and cobalt contents necessary to obtain the lowest expansion possible consistent with inflection temperatures between 200° and 600°C. (392° and 1112°F.) as well as the minimum and mean expansion coefficients obtainable in such alloys in the range where equations 4 and 5 are applicable. In calculating the data, the manganese and carbon contents have been assumed to be 0.5% and 0.2% respectively in order to approximate the percentages of these elements which are likely

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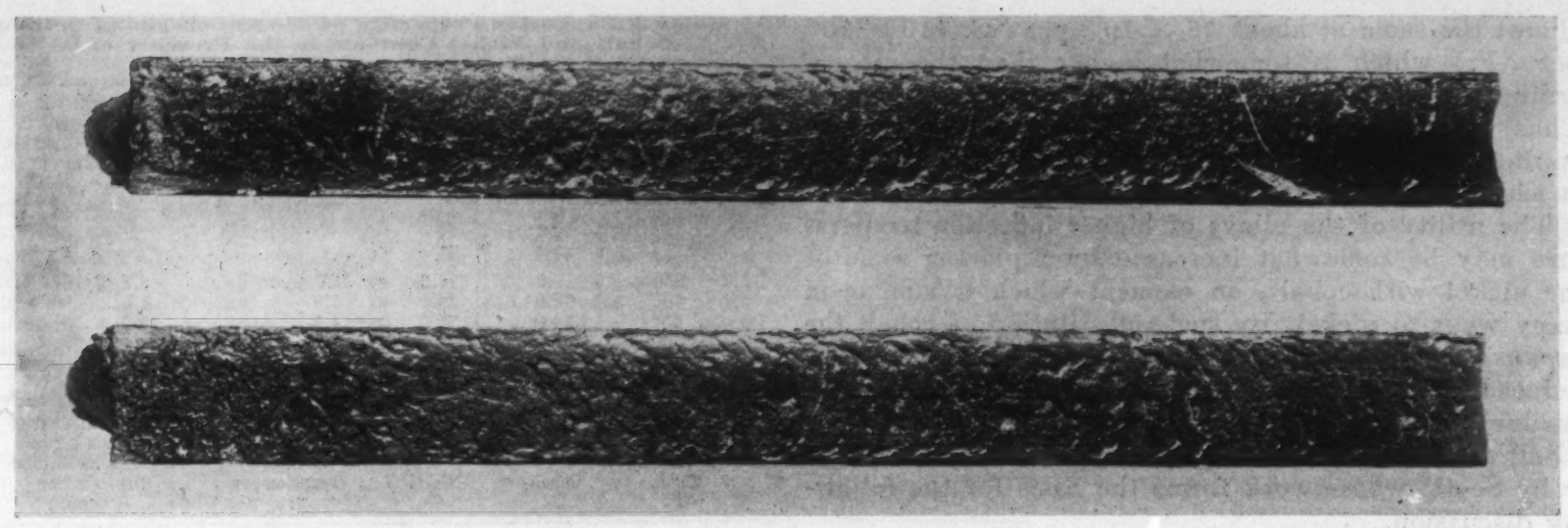


Fig. 1. Cast Silicon Bar.

Some Properties of PURE SILICON

By R. L. TEMPLIN*

SILICON is the second most abundant element in the earth. It plays a very important part as a metallic constituent in many of our most widely used alloys in both the ferrous and non-ferrous metals. In view of these facts it is rather surprising to find so little information concerning the properties of the metal in the technical literature. Perhaps the main reason for the absence of such information is to be found in the difficulties contingent upon the production of the pure metal in any considerable quantity. Another reason might well be that tests on samples of relatively high purity have indicated no really interesting properties for the alloys of high silicon content.

Mechanical property tests of aluminum-silicon alloys, containing various amounts of silicon, up to 13%, have shown that silicon has a distinct effect upon the modulus of elasticity, the alloy containing 13% silicon having a modulus of about 11,000,000 lbs./in.^{2}, or an increase of 10% in stiffness over that of pure aluminum. Out of consideration of this rather remarkable increase in modulus arose the question, "What is Young's modulus for pure metallic silicon?" A careful search of the technical literature failed to reveal any answer.

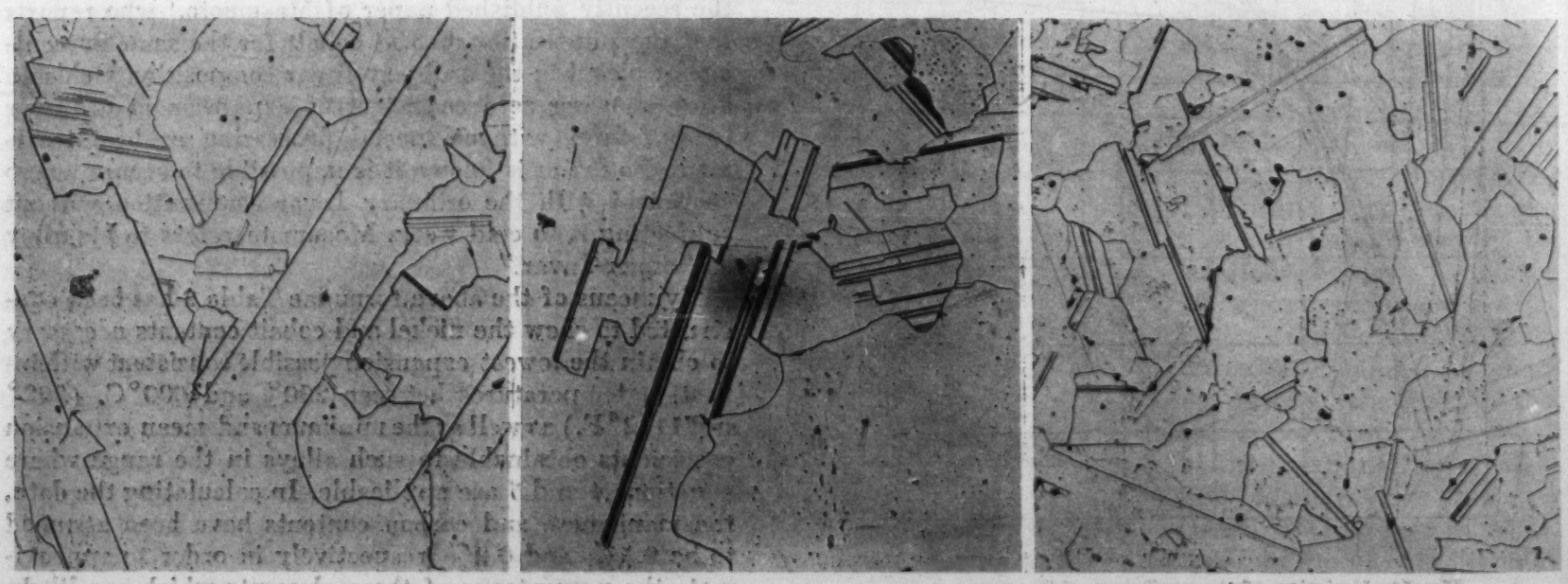
Since there was available a limited amount of supposedly very pure silicon, tests were made not only for the purpose of determining Young's modulus for the material but also such other properties as could be readily measured.

A careful chemical analysis of the metal showed it to be approximately 99.41% pure silicon and the impurities present in amounts as follows:

Fe	0.29%
Al	0.15
Cr	0.05
Ti	0.05
Mn	0.02
Cu	0.01
V	0.01
Mg	0.01
Ni	0.00
Si (by diff.)	99.41

A thorough analysis with the Hilger spectrograph showed, in addition to the elements just mentioned, traces

*Chief Engineer of Tests, Aluminum Company of America.



A B C

Fig. 2. Photomicrographs of Cast Silicon.

of the following:

Be
Ca
Ag
Li
Pb
Na

The metal which is appreciably lighter than aluminum and but little heavier than magnesium appears quite different from either of these two metals. Its dark gray or gun-metal color seems to belong more to the heavy metals.

For the mechanical property and metallographic tests the metal was cast in a cold graphite mold so as to give specimens 1 in. square by about 12 in. long. Two views of one of the chill cast specimens are shown in Fig. 1. One of the specimens was then prepared for compression testing by grinding. This operation was carried out with considerable difficulty because of the great hardness and the extreme brittleness of the metal. Finally, however, a compression specimen 0.97 in. × 0.97 in. × 3.55 in. was obtained with flat parallel surfaces.

The compression tests were carried out using a 20,000-lb. capacity Amsler testing machine and a Martens mirror type 2-in. extensometer. A small piece of thin aluminum foil was placed between the knife edges of the extensometer and the specimen to prevent damage to the instrument and at the same time enable the instrument to function properly on such a hard, smooth surface. This scheme of attaching extensometers to extremely hard metallic specimens has been found to give very satisfactory results. The specimen and testing apparatus, ready for test, are shown in Fig. 3 and a close-up view of the specimen in Fig. 4.

Load was applied to the specimen in increments of 1000 lbs./in.^{2} and the corresponding strains measured independently on opposite sides of the specimen up to a maximum of 9000 lbs./in.^{2}. The results from the two sets of readings were then averaged and plotted using the scheme suggested by Dr. L. B. Tuckerman.[1] From the data it appears that Young's modulus is about 16,350,000 lbs./in.^{2}, assuming that the value in compression is the same as in tension.

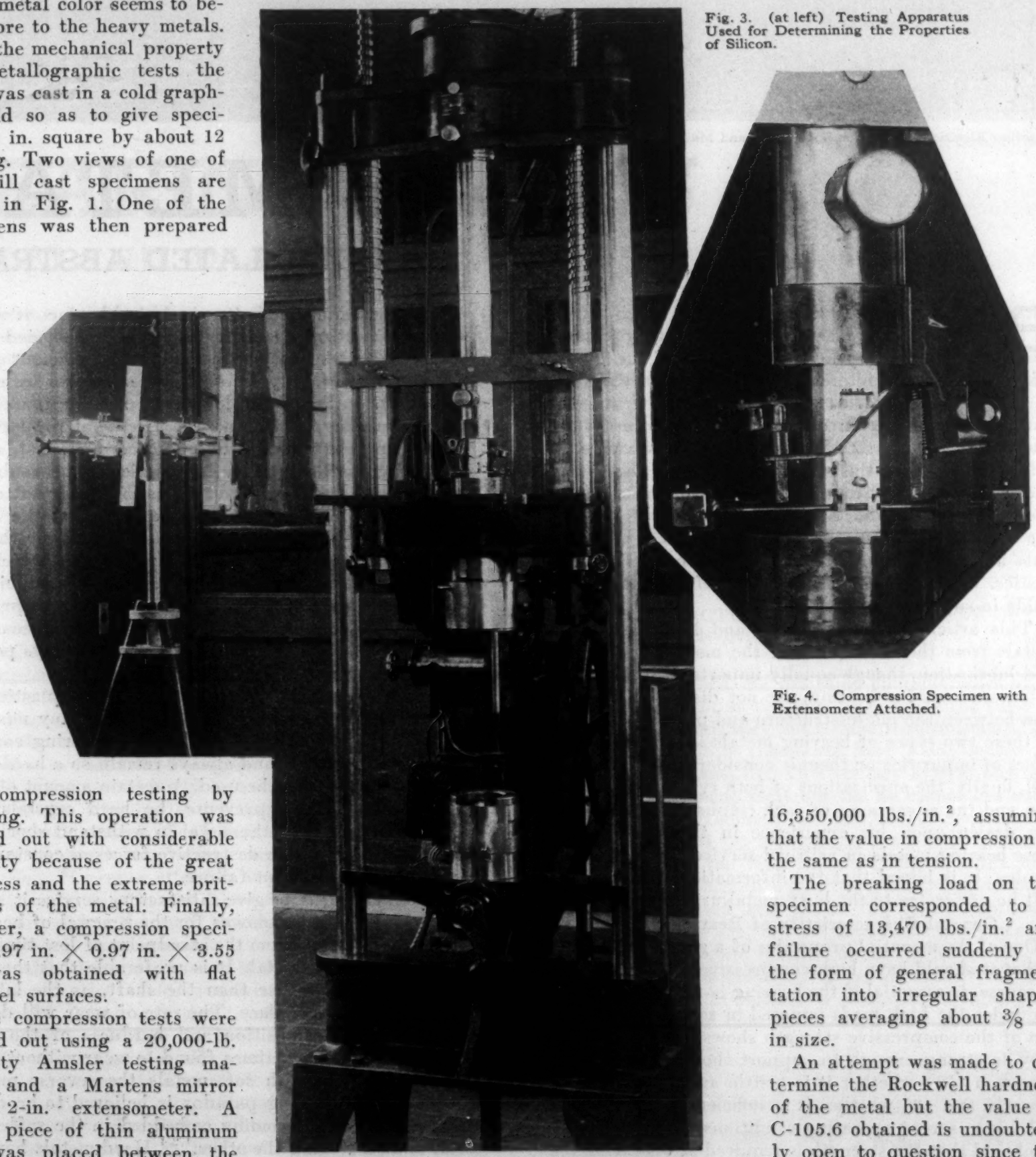


Fig. 3. (at left) Testing Apparatus Used for Determining the Properties of Silicon.

Fig. 4. Compression Specimen with Extensometer Attached.

The breaking load on the specimen corresponded to a stress of 13,470 lbs./in.^{2} and failure occurred suddenly in the form of general fragmentation into irregular shaped pieces averaging about 3/8 in. in size.

An attempt was made to determine the Rockwell hardness of the metal but the value of C-105.6 obtained is undoubtedly open to question since the metal spalled considerably around the diamond penetrator. The use of lighter loads did not remedy this trouble but the value just given serves to indicate the extreme hardness of the metal. It scratches glass easily but sharp corners or edges spall or chip easily.

A ground surface of one of the cast specimens was etched with 5% HF — % HNO_3 (by volume) and ex-

[1] Proceedings American Society for Testing Materials. Vol. 29, Part II, 1929, page 538.

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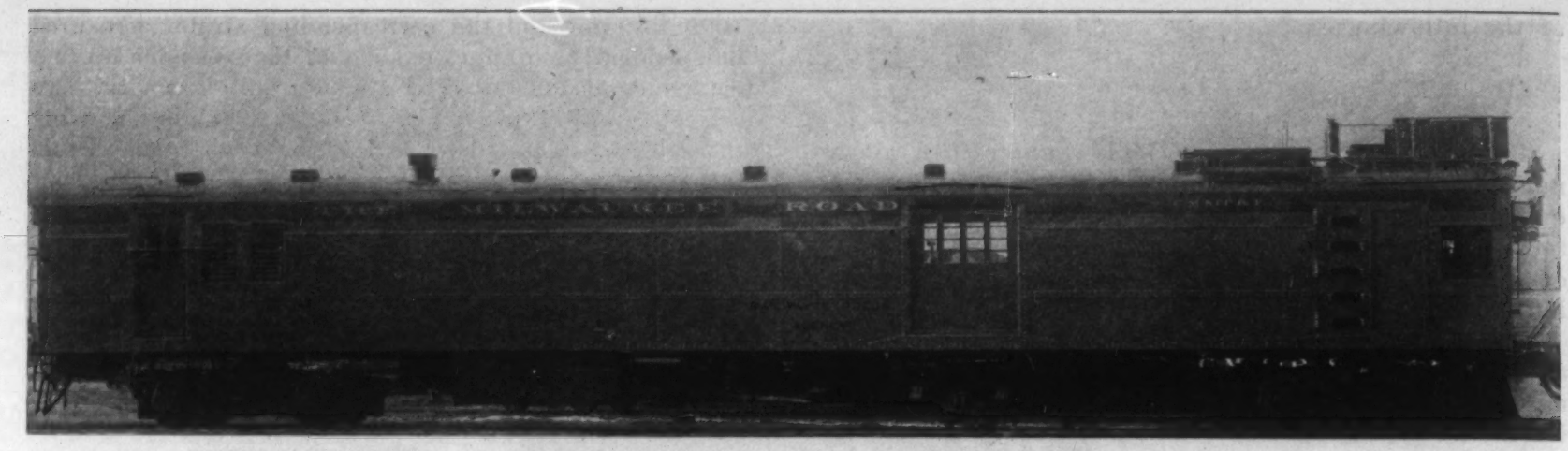


Gasoline Electric Combination Locomotive and Mail Car.

WHITE METAL

A CORRELATED ABSTRACT

BEARING METALS have received much attention from engineers, chemists, and metallurgists during the past century and, as a result of the diversity of viewpoints and interests, information on the subject is widely disseminated through technical literature. But even though this is an old and very important subject there is no book, so far as the author is aware, that adequately covers this field and presents the essential facts in a systematic and correlated manner. One who seeks information on bearings must, therefore, search the literature, and a good library with files of many journals must be available to enable one to do the subject justice. Corse's[50] recent book will be found an excellent guide in such an undertaking.

This article presents the tin and lead base bearing metals from the view point of the metallurgist. Design and lubrication, though equally important in the successful operation of a bearing, are not discussed. The relation between the micro-structure and physical properties of these two types of bearing metals is pointed out; the effect of impurities on them is considered in some detail; and, finally, the applications of both types is given attention and the advantages of each emphasized. The author has drawn upon his experience in the application of these bearing metals in railroad service for practical examples. It is hoped that the information presented here will be of service to the busy metallurgist and engineer.

General Characteristics of Bearing Metals

One of the essential properties of a good bearing metal is that it should have high compressive strength.[1,2] This, of course, is essential if the bearing is not to be squeezed out under the high loads imposed in service. Determination of the compressive strength shows; (1) whether the alloy is strong enough to support the load without deformation; (2) whether it is brittle and has a tendency to crack; and (3) whether it is sufficiently plastic to run cool under severe operating conditions. It should be remembered that the strength is required at operating temperatures and this may be widely different from the strength observed at room temperatures. Furthermore, it is impractical to use the compressive strengths, found in the literature, per se for the purpose of estimating the resistance of linings to the loads applied in service. This is because the apparent limit of proportionality rises quite appreciably as the ratio of area to height of sample under test increases. This ratio in the A.S.T.M. standard specimen is very low.

Low coefficient of friction is desirable since it reduces wear and heating as well as the power consumed by the bearing.[3] But the alloy with the lowest coefficient of friction is not necessarily the best. Other factors are equally important. In an ideally lubricated bearing there would be no metallic contact and the frictional properties of the bearing metal would be of no account. But, as this condition is not attainable in practice, some rubbing of the metals takes place and the less friction that accompanies it the better. One might expect that the harder and smoother the surfaces in contact the lower the friction would be and the higher the pressure at which seizing would take place; so that from this standpoint the harder bearing alloys would be the better. In practical bearings some compromise has to be made because of the influence of other factors, so it is not always possible to use the harder alloys.

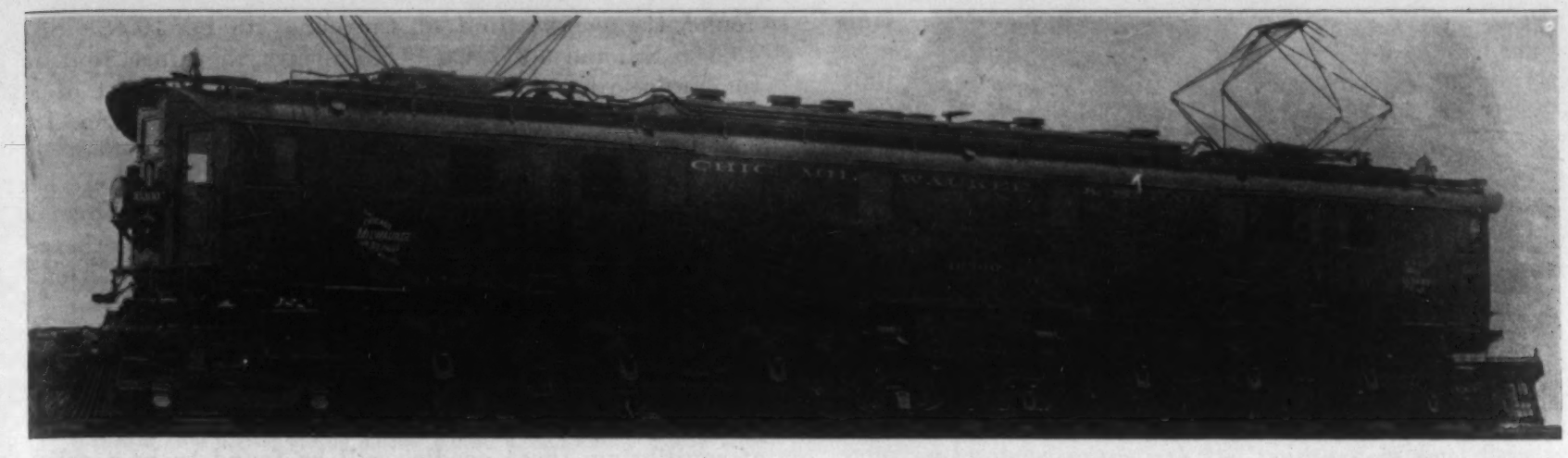
A bearing metal should have sufficient plasticity to allow it to deform enough to take care of any misalignment of the bearing or shaft.[1] If the bearing could be set up perfectly true and always remain so a harder and stronger matrix could be used. A certain amount of plasticity in the matrix prevents the hard crystals from cracking and enables the metal to withstand shocks and bending, as well as the destructive forces of constant and rapid vibration, without failure.

If the bearing is to give satisfactory service it should have a long life. Shut-downs for the renewal of bearings are far more costly from the standpoint of lost time than of cost of bearing metal. It is preferable that the bearing should wear rather than the shaft, as the latter is more expensive to replace. The rate of wear will depend partly on the composition and hardness of the alloy. Hard metals are sometimes found to wear without wearing the journal. With soft metals the reverse may be the case. This seeming paradox is believed to be due to abrasive particles becoming embedded in the softer material and scratching the other.[1,2,4] Hard metals have the disadvantage that if there is any tendency to heat they heat more rapidly and consequently wear more rapidly. Because of the greater strength of the hard alloys more energy is involved in tearing off the minute surface projections and irregularities. This energy is manifested as heat. The situation is entirely analagous to machining hard and soft metals; the harder the metal the greater the heat generated in machining it.

High thermal diffusivity is desirable in a bearing and is more important in the first stages of "running in"

*Chief Chemist, Chicago, Milwaukee, St. Paul & Pacific Railroad Company.

Second Part of this Paper will appear in the July issue.



Large Electric Locomotive.

BEARING ALLOYS

By LELAND E. GRANT*

when there is considerable wear of both the journal and the bearing. By diffusivity is meant the value k/c where k is the thermal conductivity of the bearing metal and c its thermal capacity per unit volume. Sometimes it is also desirable that the bearing should be a good conductor of electricity as in trolley car bearings and some other uncommon cases. Good thermal diffusivity depends not only on the composition of the lining but also upon good adherence to the backing. If the adhesion is poor oil will work in between the bearing and the back and retard the flow of heat ultimately causing failure.[6] In the experience of the author this has been one of the most frequent causes of failure in both tin and lead-base bearings. It can be avoided by good shop practice and attention to casting conditions. Another cause of the separation of the lining from the back is improper coefficient of expansion. On the other hand it may also be the cause of binding if the expansion is so great as to take up all of the clearance. These factors must be taken into account in the design.

In order to facilitate fitting the bearing as accurately as possible the metal should be easily worked. This permits of proper scraping and fitting as well as easy cutting of the oil grooves. Good casting properties also are desirable to avoid blow holes, excessive shrinkage, and segregation. If proper attention is given to pouring temperature, to having the mold and mandrel heated to the right point, and to thorough tinning of the back, casting difficulties will be minimized.

From the above discussion it is clear that bearing metals must meet varied requirements. They must be hard yet soft, tough and strong, yet plastic and compressible enough to yield to the load. It seems obvious that no uniform homogeneous alloy can successfully meet all of these requirements. The result is that practically all bearing metals are a composite of several constituents quite uniformly distributed. The best white bearing metals have a more or less soft and plastic matrix through which is dispersed one or more hard constituents. It is believed by some that plasticity in the matrix permits the lining to be deformed in accordance with the alignment and that the function of the harder crystals is to carry the load. Carrying this reasoning further it has been suggested that the soft matrix wears away more rapidly than the hard crystals thus producing shallow channels which serve to distribute the lubricant and at the same time to retain a certain amount of it to lubricate the shaft when it is first started up. Rosenhain[10] and others deny that such localized wear occurs. Examination of the wearing surface of a bearing with a microscope, using conical illumination, certainly does not confirm the theory. It appears better, therefore, to consider the hard crystals as being valuable because of the added strength and resistance to deformation and wear which they impart. The presence of the softer matrix surrounding the hard and relatively brittle crystals prevents them cracking under impact or sudden loads. It is advantageous when possible to have the hardness of the hardest component in the bearing the same as or at least not any harder than the journal so that mutual polishing rather than abrasion will take place.

PART I. STRUCTURE AND PROPERTIES OF TIN-BASE BABBITTS

Microstructure

Having ascertained the desirable characteristics of a bearing metal, attention can now be given to the various types to see how well they meet these requirements. The Sn base babbitts will be considered first. These consist of alloys of Sn, Sb, and Cu. This ternary system has not been investigated completely but the Sn corner has been quite thoroughly examined and this covers most of the high Sn alloys used for bearing purposes. Fig. 1 shows the Sn corner of the diagram according to Ellis and Karelitz.[8] This is not an equilibrium diagram but only a structural diagram and shows the results obtained when the alloys are cast but not annealed. Alloys in area ABDC have the δ solid solution of the Sn-Sb system, in which some Cu is dissolved, and the eutectic of the Cu-Sn system. The solid solution is composed of light gray granules while the eutectic is dark and increases in

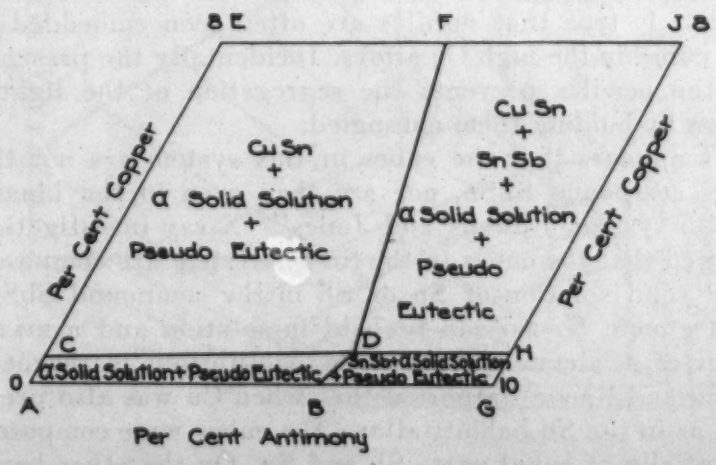


Fig. 1. Structural Diagram of the Useful Bearing Metals of the Tin-Antimony-Copper System.

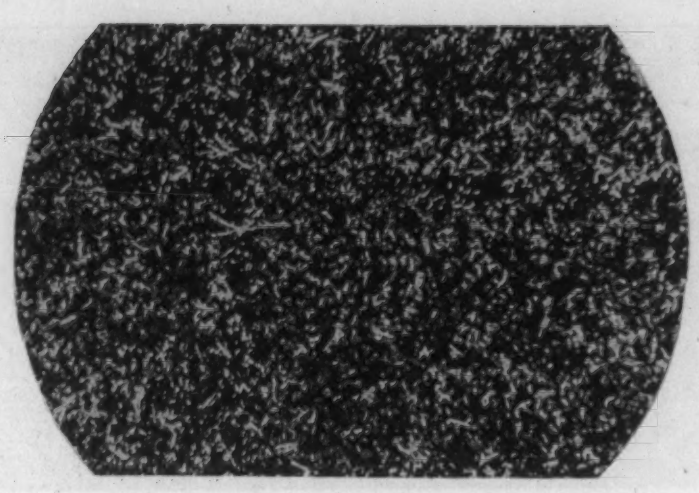


Fig. 2. Tin Base Babbitt. As 0.12%, Sb 6.22%, Cu 3.36%, Sn 90.13%, Pb trace. Brinell 21.9. Poured at 800°F. All specimens etched in accordance with the recommendations of Vilella.[54] 100x.

quantity with the Sn. (Prolonged annealing effaces this structure and leaves the alloy a homogeneous solid solution supporting crystallites of CuSn.). The solid solution is here called α to distinguish it from the solid solution of the Sn-Sb system. The eutectic is termed a pseudo-eutectic because it is not a eutectic of Cu and Sn, but one between Sn and the compound CuSn. The narrow field in the Cu-Sn diagram at the composition corresponding to CuSn is regarded by some as a solid solution, termed ε, while others consider it as the compound.

Alloys in area BGHD, as cast, comprise primary SbSn and α solid solution. They show no eutectic in the microstructures although they do not become solid until the eutectic temperature of the Cu-Sn system is reached. Suitable annealing treatment undoubtedly would reveal the eutectic.

The alloys in area CDFE, as cast, comprise the 2 primary constituents CuSn and α solid solution, and in addition the Cu-CuSn eutectic. The proportion of eutectic decreases as the Sb increases. In these alloys the dark areas represent the eutectic, the light areas the solid solution, and the white needles primary compound CuSn. Fig. 2 shows an alloy in this field. Only a small amount of eutectic is present.

The structure which results from casting any of the alloys in this system depends on the rate of cooling as well as on the composition. Rapid cooling of alloys in the neighborhood of line BDF suppresses the formation of SbSn cubes. Slow cooling promotes the formation of large cubes.

In the high Cu alloys there is a distinct tendency for the cubes to be larger, although the size of the cubes depends more on the mold temperature than on the casting temperature. The distribution of the CuSn crystals on the other hand depends more on the casting temperature. It appears as though the primary precipitation of the CuSn needles facilitates the precipitation of SbSn cubes and it is true that needles are often seen embedded in the cubes in the high Cu alloys. Incidentally the presence of the needles prevents the segregation of the lighter cubes by holding them entangled.

It appears that the cubes in this system are not the pure compound SbSn, nor are they even in the binary Sn-Sb system. Bowens and Jones'[17] X-ray investigation showed that the cubes in the Sn-Sb system are composed of a solid solution of Sn or Sb in the compound SbSn. Ten atomic % Sn can be held in solution and a maximum of 4 atomic % Sb when equilibrium is reached. Heyn and Bauer[18] reported that when Cu was also present, as in the Sn babbitt alloys, the cubes were composed essentially of equal parts Sb and Sn. On the other hand in Pb-base babbitts to which Cu had been added they found the composition of the cubes to be 50.4% Sb, 43.5% Sn, and 5.3% Cu.[19] It appears, therefore, that in the Sn-base bearing metals the cubes must consist of a solid solution of Cu and Sn in the compound SbSn. In commercial Sn-base bearing alloys, as cast, it is not to be expected that the cubes will have in solution the amount of Sn or Cu that is present under equilibrium conditions. The metal held in solid solution will, therefore, vary with the casting conditions and may be absent entirely.

Ellis and Karelitz[27] have raised the question as to whether or not the CuSn needles are really that compound in view of the fact that the existence of the compound is still to be confirmed. They think that in a state of equilibrium these needles will be found to be a solid solution (ε) but that in the cast condition they may be the compound.

Physical Properties

Having considered the micro-structure a correlation can now be made between the structure and the corresponding physical properties. One of the most important properties of these alloys is their strength in compression. Table I from work by Ellis and Karelitz[8] gives the compressive strength of various alloys as well as the Brinell hardness numbers. The falling off in hardness with an increase in temperature should be especially noted. The Brinell values were obtained using a 500 kg. load and a 10 mm. ball, except those marked with an asterisk which were obtained with a 350 kg. load. The ultimate strength was taken as the load required to compress the test piece 0.25 inch per inch of length. The increasing strength and hardness with additions of either Sb or Cu are noteworthy. Fig. 3 shows that the hardness rises quite rapidly with the addition of Sb up to about 7.5%. Beyond this the curves flatten out. Changes in hardness due to Cu are smaller. Since there is practically a linear relationship between hardness and compressive strength, it is apparent that the effect of these elements on the ultimate strength is similar to their effect on the hardness. The Sb-Sn cubes are, therefore, more effective in producing compressive strength although the Cu-Sn compound adds appreciably to the strength of the metal. The rate of increase in strength falls off with the appearance of CuSn needles and this is more pronounced at elevated temperatures. Similarly, the addition of Sb beyond that required to produce the cubes does not notably increase the strength of the alloys. For babbitts that are to operate above 75° C. some authori-

Table I. Physical properties of tin, antimony, copper alloys

Composition			Ultimate Strength	Brinell Hardness Number	
Sb	Cu	Sn	lbs./in.^{2}	20°C.	75°C.
2.26	0.51	Remainder	7560	9.5	5.9*
2.12	1.05	"	8540	11.3	7.3*
2.18	2.09	"	8880	12.3	7.5*
2.19	4.06	"	10000	13.0	8.6*
2.25	7.30	"	12080	15.3	11.5
4.59	0.47	"	9360	12.1	8.3*
4.26	1.06	"	10680	14.7	9.0
4.07	2.07	"	10920	15.0	8.1
4.10	4.13	"	12020	16.7	9.9
4.21	7.60	"	13500	20.8	12.3
6.06	0.49	"	11500	14.6	8.3
6.05	1.05	"	12880	17.0	10.0
6.40	2.16	"	13480	19.2	11.1
6.10	4.11	"	14040	19.5	11.7
6.24	7.90	"	16400	26.6	14.6
8.57	0.56	"	13960	18.6	10.6
7.98	1.06	"	14260	19.9	10.9
8.14	2.12	"	15180	21.7	13.2
8.15	4.12	"	15560	21.9	14.5
8.35	7.72	"	16880	26.1	15.8
10.59	0.53	"	13840	18.7	11.9
10.14	1.08	"	14000	20.8	11.5
10.14	2.12	"	14420	20.8	13.8
10.01	3.88	"	16040	22.6	14.6
9.95	7.38	"	18420	30.4	17.4

*350 kg. load.

Table II. Pouring temperature and hardness of A.S.T.M. babbitts

A.S.T.M. No.	Sn	Sb	Cu	Pb	Brinell 20°C.	Pouring Temp. °C.
1	91	4.5	4.5		17	441
2	89	7.5	3.5		24.5	424
3	83.3	8.3	8.3		27	491
4	75	12	3	10	24.5	377

Table III. Effect of impurities on the hardness of tin

No.	Pb	Sb	Cu	Bi	As	S	Fe	Ag Au Zn	Total Impurities	Brinell No.
1	0.0025	0.0031	0.0004	0.0004	0.0000	0.0002	0.0016	0.0000	0.0082	5.4
2	0.0371	0.0210	0.0014	0.0048	0.0113	0.0015	0.0170	0.0000	0.0941	8.8
3	0.0380	0.0400	0.0120	0.0030	0.0500	0.0000	0.0020	trace	0.1450	9.6
4	0.0600	0.0233	0.0360	0.0030	0.0500	0.0060	0.0110	0.0010	0.1903	8.1
5	0.0110	.....	0.0020	0.0020	0.0020	0.0040	0.2060	0.0000	0.2270	5.5
6	0.0580	0.0200	0.0740	0.1600	0.0150	0.0030	0.0070	0.0140	0.3510	9.9
7	0.7140	0.0200	0.0160	0.0560	0.0000	0.0010	0.0050	0.0140	0.8260	9.6
8	0.1570	0.0740	0.2740	0.3300	0.1000	0.0040	0.0050	0.0000	0.9480	12.8
9	0.1540	0.1100	0.4730	0.0700	0.0300	0.0040	0.0380	0.0130	0.8920	17.0

ties consider that the Cu content should not be high because of the relative brittleness of the alloys.

Ellis and Karelitz[8] found an empirical relationship between Brinell numbers and ultimate strength and believed that the hardness values satisfactorily express the mechanical properties of the babbitts. An investigation by K. Ito[20] indicates that the hardness varies consistently over a wide range of temperature. The alloy of 88.8 Sn, 7.4 Sb, 3.7 Cu had a Brinell hardness of 52 at −49° C.; 31.5 at 18° C.; and 10.8 at 145° C. A linear relation was found between the logarithm of the Brinell hardness number and the temperature in °C. Hardness values reported by other investigators plot equally close to a straight line.

It is clear from Ellis and Karelitz's[8] work that the rate of cooling has a marked effect on the properties of babbitts since it affects the structure. Few investigations have been made along this line but Kaul[21] states that the rate of cooling rather than the casting temperature determines the hardness of the babbitts. Large SbSn cubes result from pouring at 510° C. while small ones are formed by pouring at 400° C. Upthegrove[22] reports on the effect of centrifugal and die casting of babbitts as follows: Centrifugally and die cast bearings offer 2 variations from the production standpoint. In both, metal temperatures and mold temperatures have to be taken into consideration. In centrifugal casting the speed of rotation enters as an additional factor. Two micrographs are shown in which the centrifugally cast metal is the coarser but he reports some users find the opposite condition to be more generally true. In the discussion of this paper Bierbaum referred to some experiments by H. Graefe[23] who found a uniform improvement in his babbitts as the pouring temperature and temperature of the backing were raised. In other words increasing the time of solidification caused an improvement in the performance of the babbitt even though there was an increased coarseness. Bierbaum believed the improvement in performance to be due to the increased amount of the hardest crystal and that it might not have been the case had a soft journal been used instead of a hard one. In practice it will be found that the size of the cubes may vary over a wide range without serious effect on the metal.

Fry and Rosenhain[24] in studying the effect of casting temperatures and mold temperatures found the temperature of sand molds to have little effect on segregation up to 60° C. at least. There was a greater number of large crystals at the top in both the sand and chill mold castings, the coarseness of which increased with the pouring temperature. This tendency of the cubes to float to the top was absent in chill castings; they showed a fine uniform structure when cast at 400° C. The chill castings were a little harder than sand castings. For an alloy of Sn 87, Sb 9, Cu 4 a pouring temperature of 300° C. was found to be too low. The proper temperature was nearer 400° C. when cuboids about 0.05 mm. on a side were formed. Bottom pouring is recommended as well as the use of generous fan shaped gates and foam collectors in order to obtain a serviceable accurate liner, free from shrinks and draws.

Darby[25] studied the fluidity of the high Sn babbitts in his general study of the A.S.T.M. babbitts and found the Sn-base metals lost their fluidity from 100° to 150° C. above their freezing points, being much inferior in this respect to the Pb-base babbitts which remain fluid almost to their freezing points. The pouring temperatures recommended by him are given in Table II. These pouring temperatures mark the points of highest fluidity in the alloys. Many large users of babbitt prefer lower temperatures than these to avoid oxidation as much as possible, but one does well to be guided by them until he is satisfied a lower temperature gives good results.

Effects of Impurities on Tin-Base Babbitts

Quite extensive studies have been made by many investigators of the effect of impurities in Sn-base babbitt, particular attention having been paid to Pb. However, before considering the effect of impurities in the babbitt metal itself, it is desirable first to consider the effect of the usual impurities on pure Sn since this leads to a better understanding of their effect on the bearing alloys. From Table III Thews[5] concludes that the hardness of the Sn is in general increased by impurities. This is in agreement with several hardness studies of ternary alloys. Zn and As have a pronounced hardening effect. The addition of only 0.24% Zn to No. 1 raised the Brinell to 11.8 while the addition of 0.055% As brought the hardness to 8.7.

Ellis and Karelitz[8] describe a similar observation. Their data for hardness and composition of pure Straits tin and a commercial tin are given in Table IV. Micrographs of these 2 metals showed that the commercial tin differed considerably from the pure tin. Instead of showing the expected polyhedral crystals it was non-uniform. White patches, probably of CuSn, were visible as well as numerous other small crystals. Two alloys were made up using these 2 grades of Sn and surprising hardness results obtained as shown in Table V. The composition was about 86% Sn, 10% Sb and 4% Cu. It is evident that the impurities in the commercial tin added appreciably to the hardness of the babbitt at room temperatures.

In discussing Upthegrove's[22] paper on "Automobile Bearing Metals" A. L. Boegehold cites an example of a pure Sn bearing being used successfully where high Sn babbitts and certain bronzes wore rapidly or failed alto-

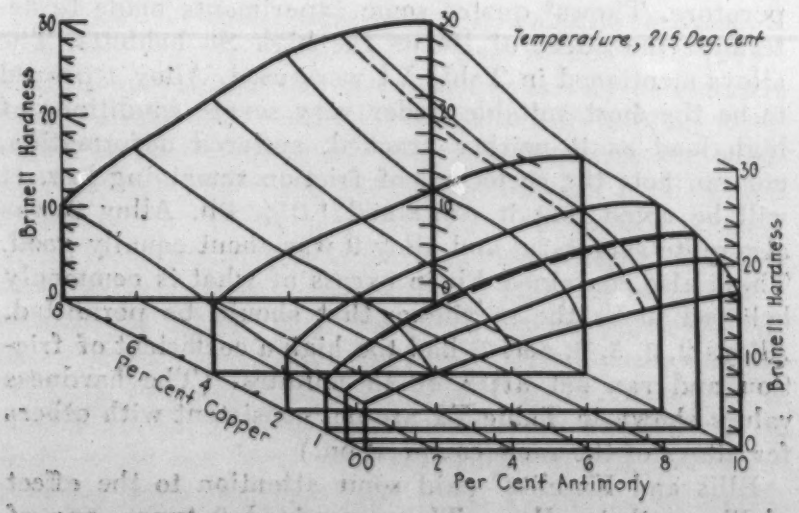


Fig. 3. Three-dimensional Figure of Hardness at Room Temperature as a Function of the Copper and Antimony Content.

gether. This is contrary to the usual ideas that a homogeneous metal is not suitable for bearing purposes. The behavior might be accounted for by the possible presence of impurities. If the Sn used were of a grade like Ellis and Karelitz's 99% commercial Sn it might well be that the hardness and lack of homonogeniety arising from the impurities had actually converted the Sn into a suitable bearing material. Boegehold[26] states that although neither analysis nor micrographs were made he believes the impurities were low enough to preclude the formation of any appreciable amounts of other crystals. Some linings were made by depositing Sn electrolytically while others were puddled on by means of a soldering iron. The lining of electrolytic Sn gave results similar to those with the puddled lining indicating that the latter may also have been quite pure Sn. The bearing conditions, however, were somewhat different from usual as the lining was only 0.005 inches thick on a steel back. Electroplated Sn coatings are being used on cast iron automotive pistons, but this service is somewhat different from that of the ordinary bearing. The information so far available on the behavior of Sn is hardly sufficient justification for rejecting the previous theory that a non-uniform lining is required, but it should induce reflection as to whether or not some significant items in the theory of bearing metals have been overlooked. It is worth while noting, too, in this connection that glass bearings have been proposed and that jewels of different kinds, though of uniform and homogeneous structure, make excellent bearings in watches. When a hard lining is used the theories proposed for soft and plastic materials do not apply. A thin lining of soft metal on a steel back should perhaps be classed with hard bearings. Generally speaking such a thin bearing would not be a practical one because very slight wear would ruin it. Yet it may be possible to find a single component system or possibly a homogeneous alloy that has the proper combination of properties to make a satisfactory bearing metal. The metallurgical theory of bearing metals seems to have been developed to explain the successful use of the alloys. Many points are not yet well understood and it does not necessarily follow that because complex alloys make good bearings that only complex alloys can be successful.

Lead

Probably the most significant and widely discussed impurity in babbitts is Pb. It is permitted only up to 0.35% in the A.S.T.M. babbitts while other specifications permit it up to 1.0%. The general belief seems to be that it is detrimental because of the decreased ductility and tenacity, the rapidly increasing tendency to develop cracks at moderate loads, and the rapid reduction in strength that accompanies an increase in temperature. Thews[5] quotes some experiments made to determine the effect of Pb on the high Sn babbitts. The alloys mentioned in Table VI were used. Alloy 1 proved to be the most suitable under very severe conditions of high load as it neither cracked, suffered deformation, nor ran hot; the coefficient of friction remaining low. It will be noted that it contained 1.0% Pb. Alloy 8 was also quite successful and alloy 9 was about equally good. These also contained Pb in excess of what is commonly believed to be the maximum that should be permitted. Alloys 2, 3, 5, 6, and 7, had too high a coefficient of friction and ran out after 40-45 minutes. (The hardness values shown in Table VI are not consistent with others for alloys of the same composition.)

Ellis and Karelitz[8] paid some attention to the effect of Pb on their alloys. They examined 2 types, one of which was low in Cu (2%) and the other high (8%), the Sb being 8% in both. In the low Cu alloy the Pb had some effect in coarsening the CuSn crystals so that they crystallized in a massive form. The lines BD and Df were pushed away from the Sn corner of the triangle as the Pb was increased. There was a practical absence of the cubes when 2.3% Pb was present. In the high Cu alloys the coarsening of the CuSn was not so definite but the tendency to extend the α field of the diagram was noticeable. The Pb increased the hardness and strength up to 1% after which there was little change. As the temperature was raised the effect became less and less, until at 125° C. it was negligible. In a later investigation the same authors[27] found in a practical test that wiping took place as a result of small areas in the upper layer of the lining reaching the solidus temperature from frictional heat. When Pb was present wiping always took place at about 180° C. the temperature of the Pb-Sn eutectic. However, this wiping did not necessarily exclude the possibility of the subsequent successful service of the bearing if the conditions which caused the wiping were remedied. Of course, if lubrication were deficient or absent entirely for a prolonged period neither the presence nor absence of a small amount of Pb in the lining would prevent failure. Freeman and Woodward[28] studied the effect of increasing amounts of Pb on the compressive strength of a babbitt of the following composition: Sn 88.9, Sb 7.6, Cu 3.5. Up to 5% lead there was but little effect with possibly a small increase up to about 1.0%. They did not believe it desirable to add Pb until an investigation had been made to determine whether or not it had a detrimental effect on the resistance to repeated impact.

Lead has been reported[29] to be beneficial up to 1% by increasing the ability of the alloy to adjust itself to the shaft. Allen[30] says that Pb softens the alloy while Clamer[2] believed that small amounts of Pb rendered the alloy harder and stiffer, lowered the melting point, and improved it in every way. Lowering the melting point is a doubtful improvement, however. Sperry[31] stated that Pb may be added up to 5-10% without injury. His alloys were probably made with antimonial Pb, at one time a by-product of silver refining.

Cowan[32] has reported the presence of minute shrinkage cavities in high Sn babbitts containing 1.5 and 3.0% Pb. These result when the Pb-Sn eutectic, which remains liquid below the point 237° C. where the remainder of the alloy freezes, solidifies at about 183° C. The contraction in volume from the liquid to the solid at room temperatures is so great that cavities are formed. When Pb was absent no cavities were found.

Jones[33] believed Pb to be beneficial when present up to 5% in a babbitt with Sn 90, Sb 8, and Cu 2. He found it to increase the hardness slightly both at room temperature and at 75° C. and, as would be expected from the increased hardness, it improved the resistance to deformation. The anti-friction properties were also improved. On an alloy of the same general composition Ellis found the hardness curve to flatten out at about 2% Pb. His hardness values are practically the same as those reported by Jones up to 2%.

From the discussion above it does not appear that a small amount of Pb is detrimental in Sn-base bearings operated at normal temperatures. It increases the hardness but promotes malleability instead of brittleness and consequently increases the ability of the lining to adjust itself to the load. Its tendency to produce shrinkage cavities and local wiping may, under conditions of impact or shock load, be the cause of some failures if it is present to the extent of more than about 2%. In bearings subjected to relatively high temperatures (150° C.

or more) Pb is detrimental because of the loss in strength it produces. But such operating conditions are not desirable for Sn-base babbitts as there is too little margin between such temperatures and the fusion point. In the author's experience no failures that could be attributed to Pb have been observed although as much as 6 or 7% Pb has not infrequently been found in bearings subjected to severe usage. (See Fig. 4.) For example, the armature bearings (sleeve type) for the 500 H.P. motors of electric locomotives operate satisfactorily with 8% Pb although they run at high speeds and especially on rough track are subject to shock and impact loads. The normal composition of the lining is Sn 83, Sb 10, Cu 6.3, Pb 0.7. A lead content of 8% is not recommended nor is it usual, as normally the lining does not contain more than ¾% lead, which is derived largely from the solder used in tinning. (See Fig. 5) The main crankshaft and connecting rod bearings in 275 H.P. engines of gas-electric cars are sometimes found to have as much as 5% Pb in the babbitt, due largely to contamination in relining, yet they do not give any more trouble than the ordinary linings with little Pb. From a practical standpoint, therefore, it appears that one must not be too hasty in explaining failures of babbitt as being due to small amounts of Pb therein. As the Pb "pick up" does not exceed 0.5% it is not necessary to restrict the lead content to 0.35%. Nor does there appear to be any necessity for using pure Sn to tin the back. Boegehold and Johnson[36] have reported that no detrimental results were observed in airplane engine bearings lined with A.S.T.M. No. 1 babbitt in which as much as 2.5% Pb was found.

Nickel

Another less common element in babbitt, and one that, strictly speaking, is not to be considered as an impurity, is Ni. It was formerly used extensively as the aftermath of its having been introduced into a certain kind of babbitt entirely for identification purposes. Not much study has been given to the effect of it on the properties of the alloy. The general opinion is it increases the ductility and eliminates the tendency to cracking without interfering with the wearing qualities. Mundey and Bissett[34] found some interesting results from the additions Ni to a babbitt of the following composition: Sn 93, Sb 3.5, Cu 3.5, as shown in Table VII. There is some irregularity especially in the elongation but the authors believed this is to be expected of alloys of this type consisting of hard crystals embedded in a soft matrix. Tests on a Thurston machine were satisfactory. When 0.4% Ni was present, the microstructure showed its effect very definitely, the formation of the typical CuSn needles being very much suppressed. The addition of the extra Cu in No. 7 partially restored the structure. From this it is apparent that the Ni dissolves in the Cu and prevents the normal production of the CuSn needles. The alloy consequently loses some of its compressive strength, which it owes to the interlocking of the CuSn needles, there being no cubes in an alloy of this composition. Any hardening effect of the Ni due to the formation of a solid solution is not sufficient to compensate for the change in structure and as a result the hardness decreases with the addition of Ni. Sperry[31] says even 1% Ni will make the metal pour sluggishly, due to the higher melting point, and that no advantage results from the presence of 0.5% Ni in the Ni babbitts on the market. His data indicate it to be detrimental rather than beneficial. Many of the so-called Ni babbitts no longer contain Ni even though they might have done so at one time. The author has never found Ni in any babbitts tested in his laboratory.

Table IV. Hardness of tin

	Straits	Commercial 99% Tin
Tin	99.95%	98.99%
Lead	0.032%	0.78%
Copper	0.005	0.12
Iron	0.010	0.02
Bismuth	0.010	0.024
Zinc	trace	trace
Brinell Number	5.0	10.3

Table V. Effect of impurities in tin on the hardness of Babbitt

	Brinell Hardness	
Temp. °C.	Straits Tin	Commercial 99% Tin
26	24.5	27.5
50	18.0	21.0
75	13.5	16.5
100	11.0	10.1
125	10.0	11.0

Table VI. Effect of lead in tin base babbitts

No.	Sn	Sb	Cu	Pb	Ni	Pouring Temp. °C.	Annealing Temp. °C.	Brinell
1	90.8	4.1	3.8	1.02	—	370	150	26
2	83.3	11.0	3.9	0.92	—	350	"	28
3	80.9	10.7	4.2	3.3	—	350	"	31
4	89.9	4.3	4.2	1.3	—	370	"	30
5	86.3	10.3	3.2	0.0	—	400	"	30
6	60.2	12.0	6.3	19.9	—	400	"	34
7	90.8	4.3	3.9	trace	0.53	400	"	20
8	87.3	7.5	4.6	0.62	—	350	"	33
9	77.5	11.2	10.0	0.75	—	400	"	31

Table VII. Effect of nickel on tin base babbitt

No.	Nickel Content	Tensile tons/in.²	Elongation 2"	Yield 0.001"	Brinell	
1	0.0	5.12	11.6%	3.57 tons/in.²	24.9	Original
2	0.1	4.6	18.0	2.85 " "	19.3	
3	0.2	4.6	12.2	2.85 " "	21.5	
4	0.3	4.4	6.1	2.57 " "	22.3	
5	0.4	4.6	11.0	3.0 " "	21.5	
6	0.5	3.6	5.7	3.0 " "	21.5	
7	1.0	4.1	15.4	2.57 " "	20.1	also 4% copper

Arsenic

Small amounts of As may be found in the high-Sn babbitts but, as in the case of Ni, the effect of this element has not been studied extensively. Freeman and Brandt[35] give some figures for the effect of As on the compressive strength and hardness of the following alloy: Sn 90.4, Sb 4.6, Cu 4.6, Pb 0.3. Up to 0.5% As there was a progressive increase in hardness both at room temperature and at 100° C. but little further increase was noted up to 3.0% As. The Brinell hardness was raised from 20 to 23.5 at 20° C. and from 9.5 to 12 at 100° C. This could probably be expected in view of the pronounced hardening of Sn by this element. It is not clear whether the As also causes brittleness since the Brinell number is not necessarily related to toughness in these alloys. The effect of As on the microstructure appears not to have been investigated. However, in view of its profound effect on the cubic SbSn crystals in Pb-base alloys it is reasonable to suppose that it would have a similar effect on the same crystals when they are present in the Sn-base alloys.

Bismuth

Bismuth is undesirable in these babbitts because it forms an eutectic with Sn melting at 135° C. (275° F.).[36] This reduces the strength excessively at elevated temperatures and causes local fusion and wiping, especially in the "running in" stage. It increases the hardness without increasing brittleness, reduces friction, and improves the casting qualities. The low melting eutectic with Sn, however, offsets all of its advantages. It is not common to find any appreciable quantities of it in the commercial alloys. Bi is not soluble in tin below 95° C. but whether or not it is completely insoluble in Sn-base babbitts does not appear to have been determined. It is soluble in Sb. If solid solutions do exist the eutectic of SnBi could not form until the solid solution concentration had been exceeded. The effect of fairly rapid cooling in reducing the solubility must also be considered. The exact quantity of Bi required to be present before

the Sn-Bi eutectic is formed does not seem to have been determined, although it is known to be a small amount.

Aluminum and Magnesium

Aluminum and Mg are sometimes added as deoxidizers and Al is said to break up the crystals. Heyn and Bauer,[18] however, concluded that though Mg and Al cause a slight increase in hardness they are superfluous and might develop harmful properties. Sperry[31] reports that Al is used up to a fraction of 1% but that it has no notable effect. Mg is used to a slight extent but its action is an undesirable one similar to that of Zn. P-Sn is sometimes used as a deoxidizer but whether or not any of the P remains in the alloy does not appear to have been reported in the literature. A little P added to the thick metal will make it more fluid.[31]

Zinc

The effect of Zn in Sn-base babbitts was studied by Freeman and Brandt.[35] Up to 1.3% it decreased the Brinell hardness from 21 to 19 at 20° C. and from 11 to 10 at 100° C. At normal temperatures it raised the yield point only a little but at 100° C. it raised the yield point 30%. Thews[5] reports that Zn increased the hardness and brittleness but that the brittleness could be eliminated without affecting the hardness by proper methods of casting. A marked effect of Zn on the microstructure was observed by Archbutt.[37] His alloy had the composition Sn 81.0, Sb 11.1, Cu 7.2, Pb 1.30, Zn 0.032, Fe 0.034, and was dead white instead of having the usual reddish tinge. Micro-examination showed the SbSn cubes to have a ruptured appearance. The addition of 0.1% Zn made the effect more pronounced and the cubes had a tendency to orient themselves in star shaped groups. The color of the ingot also changed. A micrograph is included to show how the cubes had been changed partly to small grains when 0.2% Zn had been added. Sperry[31] found Zn to be injurious as babbitts containing it were sluggish and had much included dross. In view of the above results the exclusion of Zn so far as practicable is justified.

Iron

Iron is undesirable as it increases both the hardness and brittleness of these alloys. It is not met with very frequently in commercial alloys.

Tin Oxide

The presence of tin oxide in these bearing metals is very uncommon. It is objectionable because of the extreme hardness of the sharp angled cubes of this constituent. Only one example of the presence of tin oxide in babbitt has ever been seen by the author and in this case the inclusions were too small and too few in number to have any marked effect on the properties of the metal.

Copper and Antimony

Copper and Sb are essential constituents of this type of alloy so that an understanding of the part each plays is desirable in order to get a clear idea how, by changing the proportions of these elements, the properties can be varied to meet different conditions. Up to about 7% Sb there are no cubes formed, all of the Sb being held in solution in the Sn. This acts to harden the matrix making it tougher and more resistant to shocks. Above 7% Sb forms SbSn cubes with the Sn and adds to the hardness somewhat but the strength increases very little. Carrying it too high will induce brittleness, especially if the cubes become so numerous as to touch each other. It is reported that this brittleness causes gradual wasting away of the metal if bearings with high Sb are operated at temperatures above normal. In general the function of the Sb is to reduce the friction, raise the liquidus temperature, and increase the strength and hardness.

Copper remains in solid solution and in the pseudo-eutectic until nearly 1% is present when it begins to show as needles of CuSn. The strength and hardness increase with the Cu but the rate of increase falls off after the needles appear. This becomes more pronounced at high temperature and high Cu content. Like Sb it raises the liquidus temperature and because of the separation and comparatively rapid growth of large CuSn needles in the molten alloys of high Cu content it is necessary to take special precautions in pouring to prevent the needles from settling to the bottom. To preserve a fine structure in bearings with high Cu content they are sometimes quenched immediately after pouring. If more than 7% Cu is present the alloy is reported to be brittle and unable to withstand high bearing pressures and shock at elevated temperatures, yet the tolerances of many specifications allow Cu above this percentage.

Table VIII. S.A.E. tin base babbitts

	No. 10	No. 11	No. 12
Tin min.	90.0%	86.0%	59.50%
Antimony	4. to 5.	6. to 7.5	9.5 to 11.5
Copper	4. to 5.	5. to 6.5	2.25 to 3.75
Lead max.	0.35	0.35	26.0
Iron max.	0.08	0.08	0.08
Bismuth	0.08	0.08	0.08
Arsenic max.	0.10	0.10	-------
Zinc & Aluminum	none	none	none

Applications

This is not the place to undertake an extensive discussion of the applications of high Sn babbitts because operating conditions vary widely and it is these conditions that determine the type of bearing metal to be used. The high Sn babbitts are especially well adapted to severe service, but because of the high cost of Sn, there has been considerable tendency to substitute other bearing metals in place of these babbitts when possible. The Pb-base alloys have been used in place of the Sn-babbitts in many applications where it was previously thought impractical to use them.

For high pressures and high speeds 90 Sn with 7 Sb and 3 Cu is recommended. It has a Brinell number of about 21. A somewhat softer alloy, used successfully for the big end bearings of air craft engines and said to be one of the best for critical and severe service, as it combines toughness and strength, is 93 Sn, 3.5 Sb, and 3.5 Cu. It has a Brinell number of 15.5.

The usual automobile specifications for engine bearings are in the order of their use; 85, 7.5, 7.5; 91, 4.5, 4.5; 89, 7.3, 3.7; 87.50, 6.75, 5.75; 90, 8, 2. A considerable range of hardness and compressive strength is involved and it appears doubtful if such a range is necessary for the service conditions involved. Navy bearings are 89 Sn, 7.3 Sb, and 3.7 Cu, with a Brinell of 22.5. Most of the compositions given, save those with under 5% Sb usually have such tolerances that the compositions may be close to line DF of the diagram. The structure accordingly will vary considerably with slight deviations in composition or casting conditions. A composition that will give a definite structure under normal variations in analysis and casting conditions is to be preferred to this. More research will have to be done to establish the specific effect of the variations in structure on the antifriction and other qualities of these bearing metals but by keeping definitely away from line DF any possible alterations will be avoided.

The hardness and pouring temperatures of the A.S.T.M. standard Sn babbitts are shown in Table II. These alloys probably are adequate for at least the majority of service conditions.

The S.A.E. lists 3 standard Sn-babbitts as shown in

Fig. 4. Tin Base Babbitt with 8% lead. Etched in Vilella's reagent. As 0.00%, Sb 8.00%, Cu 4.05%, Sn 79.08%, Pb 8.74%. 100X.

Fig. 5. Lining of Armature Bearing of Electric Locomotive. As 0.02%, Sb 10.35%, Cu 6.17%, Pb 0.68%, Sn 82.41%. 100X.

Fig. 6. S.A.E. No. 11. Babbitt Cast at 425°C. As 0.00%, Sb 8.66%, Cu 5.00%, Sn 86.15%. Brinell 23.5. 100X.

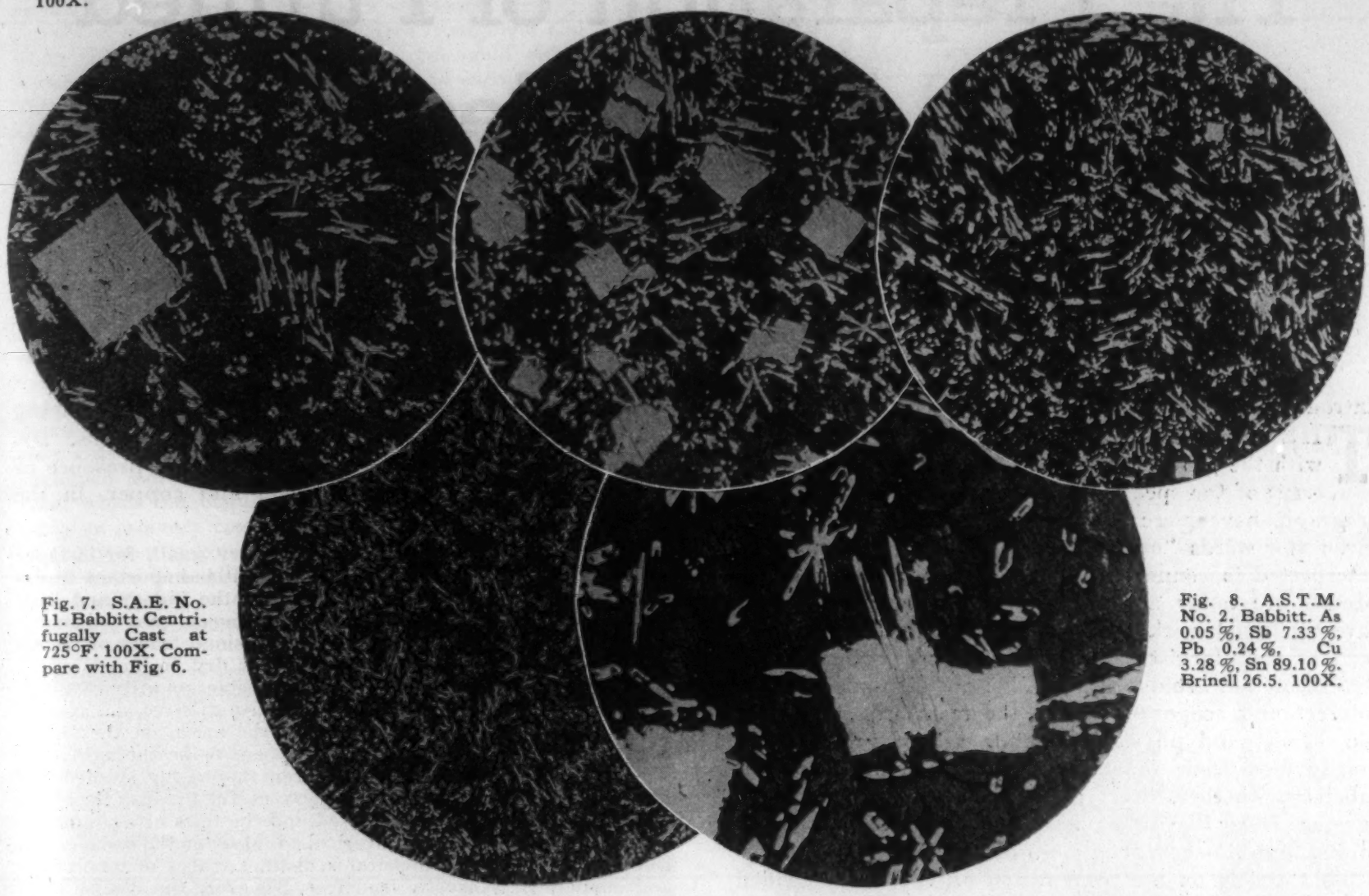


Fig. 7. S.A.E. No. 11. Babbitt Centrifugally Cast at 725°F. 100X. Compare with Fig. 6.

Fig. 8. A.S.T.M. No. 2. Babbitt. As 0.05%, Sb 7.33%, Pb 0.24%, Cu 3.28%, Sn 89.10%. Brinell 26.5. 100X.

Table VIII. No. 10 is very fluid and may be used for bronze-backed bearings, particularly for thin linings such as are used in aircraft, electric motors, and generators. No. 11 is a rather hard babbitt and may be used for lining connecting rod and shaft bearings which are subject to heavy pressures. It is used extensively for automotive engine bearings. Its wiping tendency is very slight. Fig. 6 shows at a magnification of 100 diameters a sample supposed to be S.A.E. No. 11 babbitt, but containing about 1% more Sb than allowed by most specifications, as cast in a connecting rod bearing. The cubes in this sample would not be present in the standard alloy. It was poured at 425° C. into a warmed liner. The S.A.E. No. 12 is a relatively cheap babbitt intended for bearings subject only to moderate pressures. Other automotive babbitt specifications are frequently based on the S.A.E. Some prefer to set the Sb and Cu both at 7.5 instead of having the Cu slightly lower as in No. 11. This composition is highly recommended but it is about as high as it is practicable to carry the Cu content.

An effort to standardize the Sn babbitts more completely appears to be very desirable. The number of alloys that can be made is enormous but they will all fall into one of the 4 groups discussed in connection with the constitutional diagram. Those in each group will differ only in the quantity of each phase present. There do not appear to be any good grounds for having the alloys so close in composition that they grade imperceptibly into each other. Probably part of the supposed superiority or inferiority of many of the alloys has been due to the presence or absence of impurities and the differences in casting conditions. If standard conditions of handling are adopted many of the variables affecting the serviceability of the metals would be eliminated with the resulting advantages. Losses on remelting are not serious if contamination and oxidation are guarded against. Good shop practice and intelligent selection of the composition for any definite set of conditions would undoubtedly eliminate much of the needless confusion associated with the large number of alloys available.

In connection with shop practice reference may profitably be made to the suggestion made by both Bultman[38] and Bierbaum[39] that the final cut on the bearing surface should be made with a diamond tool. If this is not done the hard particles of SbSn may be pulled out and the efficiency of the surface destroyed. Slow running in is then necessary to wear down the surface layer to a new set of cubic crystals. This probably applies in some degree to other bearing metals as well as to the Sn-base, since they all consist of hard particles in a soft matrix. Certainly the principle applies to railroad car journal bearings. When these are properly broached they give but little trouble in running in. If they are not broached or are improperly broached many hot bearings are inevitable. Passenger car bearings are broached, a steel cutting edge being used. Freight car bearings are not often broached because the expense involved in so doing is not warranted. Another advantage of using the diamond tool is in the accuracy of the bore. When properly used no hand fitting is necessary as a bearing contact of 75% or more is produced. Close tolerances and good bearing contact are essential in mass production work. Recently improved broaching machines have been produced on which a sharp clean cut and accurate bore is obtained on journal bearings.

(Continued on Page 150)

The Preparation of Purified Gold Electrodes for the Spectrograph

BY THOMAS A. WRIGHT*

Introduction

THE WORDS "purity" and "traces," coincident with the growing appreciation of the unique advantages of the spectroscope and particularly the spectrograph, have more than ever, become relative terms. Even the words "minute" and "infinitesimal" must be interpreted in connection with the subject under study. Metals are today as never before the object of much investigational work by food and biological chemists as well as metallurgists. To the first, food contamination, its extent and avoidance make the question one of joint interest and coöperation with the metallurgist. To the bio-chemist and physician, metals are of interest primarily from their functional influence on the body metabolism, whether direct or catalytic, beneficial or the reverse. Here the direct need of coöperation of metallurgist and bio-chemist is more obscure.

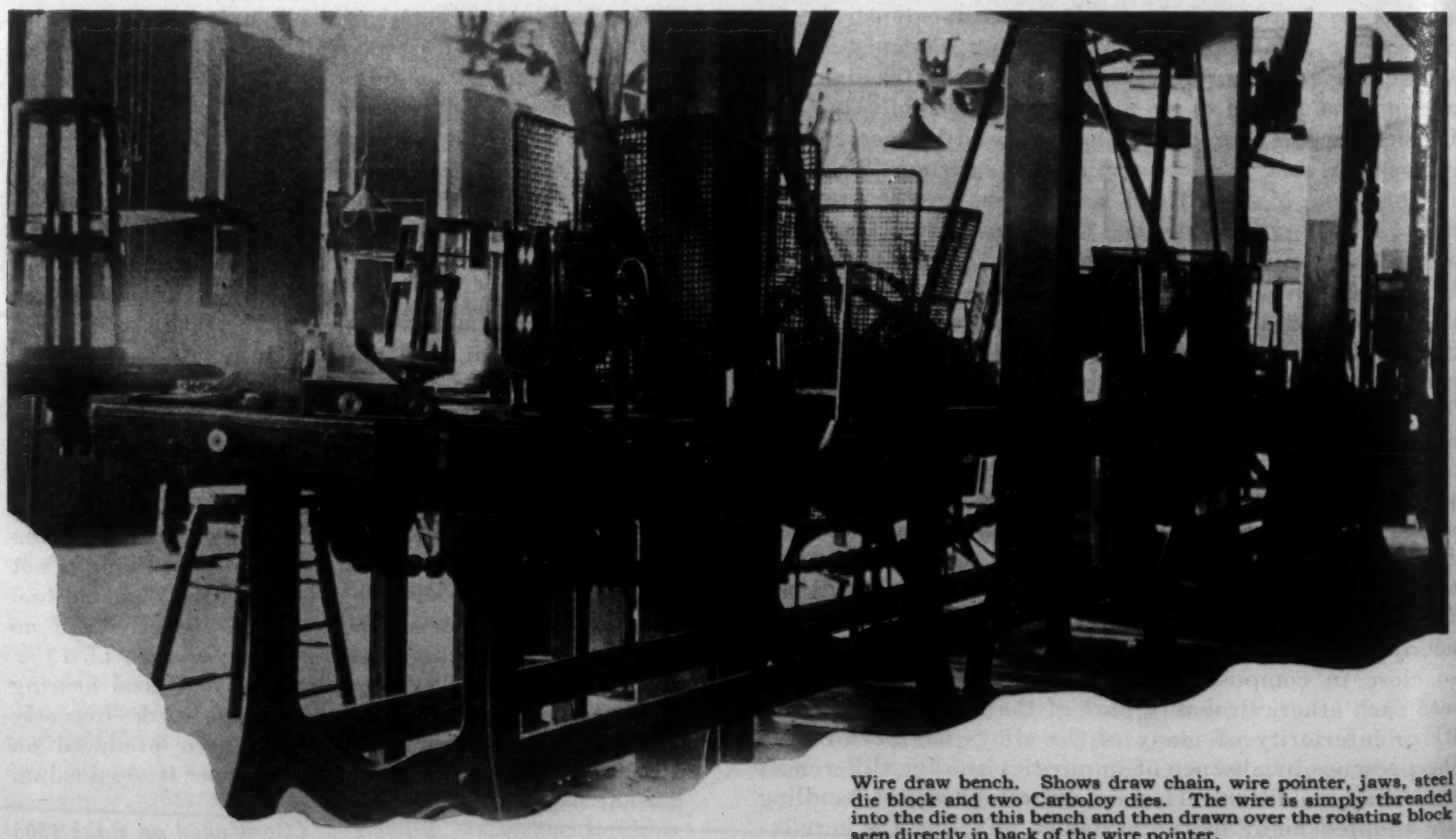
This article on the preparation of specially purified gold wire for use with the spectrograph at the Institute of Cancer Research gives an example of such need.

The following informative note by Dr. Francis Carter Wood† will explain one of the reasons for the making of gold as free as possible from contaminations. Dr. Wood has been studying the question of the presence of heavy metals, such as lead, silver and copper, in the tissues of small animals.

The amount of material available is very small, for instance in a mouse weighing only an ounce, for it is important to determine whether the silver is present in the kidney and liver and also in the tumor with which this mouse may be inoculated. The only way to detect the infinitesimal traces of metals of this type is to ash the tissues, wet or dry, in quartz crucibles, take up the ash in as small as possible quantity of nitric acid and electrolyze the concentrated solution of an amount not to exceed 10 cc. so as to obtain the metal on the tip of a wire of suitable material. Gold happens to be the most convenient because its spectrum has been thoroughly studied and is relatively simple. Platinum is less useful because its spark spectrum is extremely complicated and the lines of contaminating elements may be easily overlooked. Most of the commercial, so-called pure gold wire contains distinct traces of both silver and copper. It is usually lead free, however, and can be used for the detection of this element. But where silver and copper are to be studied, it is necessary to have gold free from these elements.

*Technical Director, Lucius Pitkin, Inc., Consulting Chemists and Metallurgists, New York City.

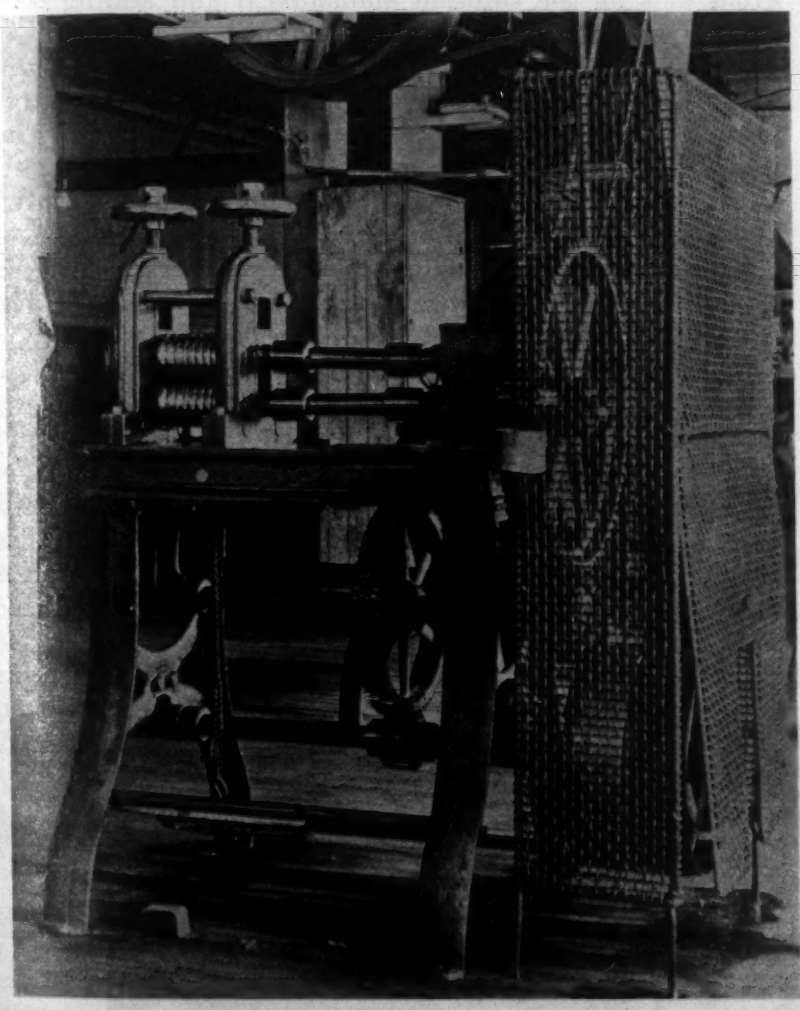
†Francis C. Wood, M.D., Director of Institute of Cancer Research, Crocker Foundation, Columbia University.



Wire draw bench. Shows draw chain, wire pointer, jaws, steel die block and two Carboloy dies. The wire is simply threaded into the die on this bench and then drawn over the rotating block seen directly in back of the wire pointer.

When the word "free" is used, it means that under the conditions of the experiments the characteristic lines of these two metals do not appear in the spark spectrum. Mr. Wright has succeeded in preparing such wire free from silver and copper when the spark is passed between two gold electrodes of Number 18 gold wire for a period not to exceed five minutes. This time is quite sufficient to volatilize lead, copper and silver deposited on the smooth surface on the tip of the wire. Such metal is rather spongy and apparently evaporates very quickly in the condensed spark which is employed. Using this material, amounts of silver, copper and lead have been detected which approximate one hundred-thousandth of a milligram.

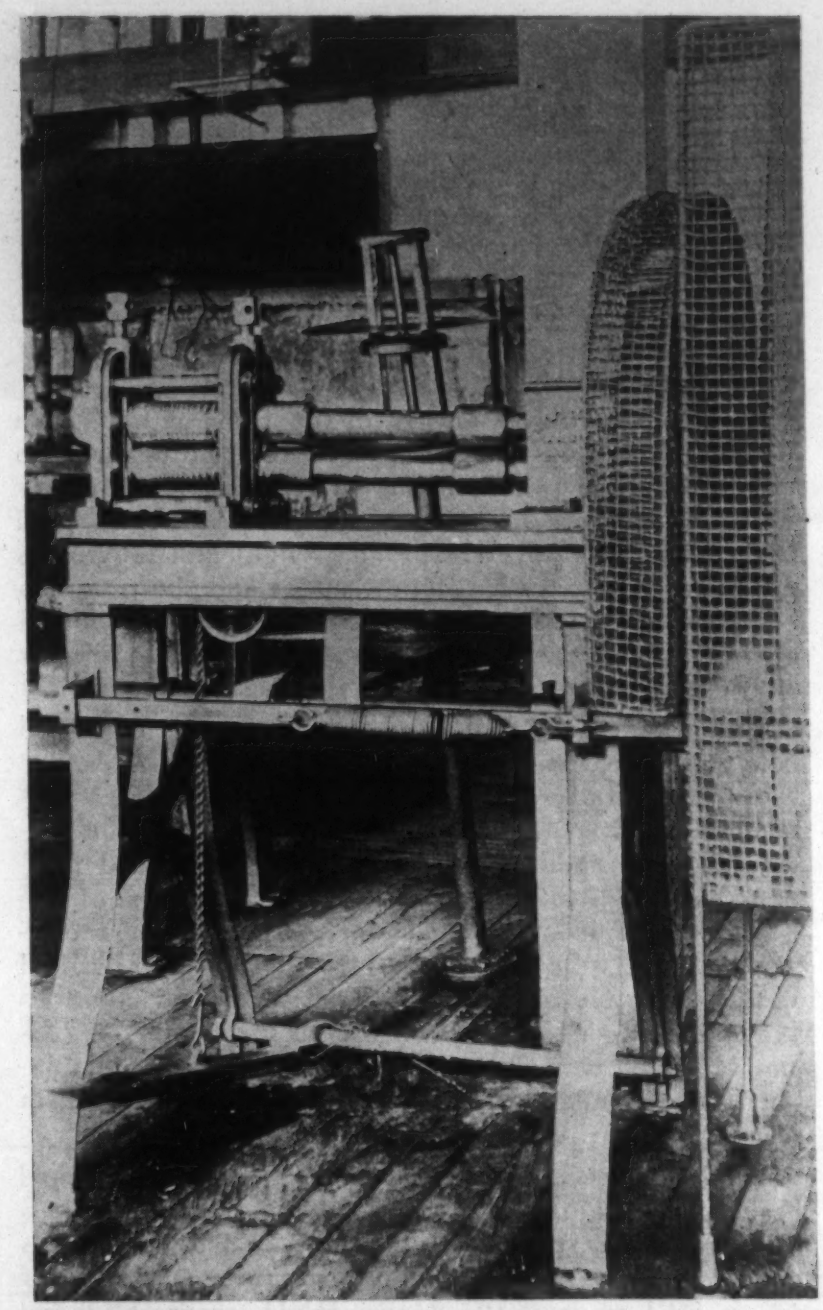
Lead is apparently a constant constituent of the body, probably derived from drinking water. While the use of lead pipes to carry water has been abandoned in the City of New York, the Croton water drawn from the taps contains sufficient lead to permit its demonstration by this method in the evaporated residue of 100 cc. of water. An interesting discovery showing the necessity for extreme caution in the application of such delicate tests was that the distilled water used in the laboratory contained more lead than the ordinary original Croton water from which the distillate was prepared. In other words, in using an ordinary commercial, laboratory still the lead content of the water is concentrated in the distillate. Hence if distilled water is used in diluting the solution before electrolysis false results will be obtained. Fifty cubic centimeters of nitric acid were evaporated and no lead found in the residue. As



Wire rod rolling mill equipped with rectangular grooved rolls. Eight passes producing rod from 0.26″ to 0.20″ square.

only a few drops of the acid are used in the process of ashing, no lead can be expected from this source. Quartz crucibles are obviously free and repeated checks have proven this fact. The lead in the Croton water evidently comes from the red lead which is used in making tight joints in the water pipes.

It also is possible to detect lead by this method in the urine of every healthy human being so far tested. The amount derived seems to be about one thousandths of a milligram per hundred cubic centimeters—a quantity which can be easily detected by electrolyzing the ash from that quantity of urine. That this lead is not derived from ethyl gasoline is shown by the fact that Dr. Wood has been able to demonstrate lead in bladder calculi removed from human beings in the New



Wire rod rolling mill equipped with rectangular grooved rolls. Twenty passes from 0.22″ to 0.08″ square.

York Hospital between the years 1855 and 1865. The pathological museum of that Hospital was distributed about 1895 and the collection of calculi which had been removed from the bladders of patients by the old surgeons of that institution were presented to Dr. Wood who has had them ever since. Practically all the calculi which have been examined contain at least one hundred thousandth of a milligram of lead per gram of calculus. Many contain considerably more. The quantity of lead precipitated in the calculus seems to depend on whether the calculus is of uric acid type or of an alkaline phosphate type. Fairchild has shown that lead can be quantitatively recovered from urine by adding a little ammonium hydrate. The precipitate of the alkaline phosphates which forms carries down the lead so completely that the method is used for quantitative analysis. The same principle no doubt applies when alkaline phosphate calculi are formed in the bladder. While modern calculi also contain lead which might be assumed to be due to contamination of the atmosphere with the combination products of ethyl lead, this demonstration proves that lead was present in the body, in traces, 70 years ago.

This method of detecting heavy metals by electrolysis is like so many other chemical processes not wholly new. It was used in 1865 to detect the presence of thallium in the medical legal examination of a case of thallium poisoning. At that time spectrographic methods were not available. The old German chemist, however, deposited the thallium by electrolysis on a platinum wire and then examined the flame spectrum as the wire burned off in a Bunsen flame. The green thallium line was easily visible in an ordinary spectroscope.

Silver and copper are not regularly present, though copper regularly and silver occasionally can be detected in the liver

where they are apparently fixed in the tissues. It is rather puzzling to know where the silver comes from. Silver salvarsan is used in the treatment of syphilis and such persons might be expected to have considerable silver in the organs. But even those persons who have never had such treatment will show traces of silver, especially in the liver. Perhaps this silver comes from the use of silverware in the household. The copper is derived from food, wheat containing a considerable quantity. Recent evidence has been brought forward to show that a minute trace of copper in combination with considerable quantities of iron in some way increases the effectiveness of the iron in treating anemia.

Solution and Precipitation of Gold

The gold used was mostly in the form of that from parted silver beads accumulated in the routine practice of the assay department of a commercial laboratory whose field covers all types of material containing gold from ore to finished alloy product. The chief impurities present, therefore, were silver, copper and the platinum group and to a lesser extent such base metals as nickel or zinc used as alloying elements in dental, jewelry alloys and the like.

The primary object as stated was to make a finished gold wire spectroscopically free of copper, silver and lead but naturally every effort was made to reduce contamination with other elements. To this end, allowance was made for about 20-25% wastage or discarded fractions and 6 ozs. of the original gold gave 4 ozs. of finished wire 0.085 inch diameter. All beakers, watch-glasses, etc. were very carefully cleaned in distilled water, the latter being used, of course, for all solutions and only reagents of known excellence employed. Almost as much care was required in avoiding contamination by reagents, dust and handling operations as in removing impurities assumed to be present.

For convenience and insurance against loss by cracked beakers, etc., the 180 g. used was divided into 9 portions of 20 g. each in 800 cc. Pyrex beakers. Each portion was dissolved in a dilute aqua regia mixture consisting of 45 cc. HCl sp.gr. 1.19—15 cc. HNO_3 sp.gr. 1.42 and 300 cc. H_2O distilled. After solution, the watch glasses were removed and the solutions evaporated to a thick syrup. All evaporations were conducted on a water-bath. 20 cc. of HCl (4 HCl-1 H_2O) was added to each, covers added until gas evolution had ceased, covers removed and the solution evaporated as before. In order to insure complete removal of the HNO_3 this treatment and evaporation was repeated 4 times. Finally the syrup was taken up with 650 cc. of hot distilled water, digested on the water-bath until all soluble matter had been taken up and then allowed to settle undisturbed for one week in a dust-free atmosphere. The precipitate, of course, was primarily AgCl with a small amount of gold, palladium, silica, etc.

The supernatant solution of gold chloride plus soluble elements was then decanted through double close textured filter paper, the first 100 cc. being repassed to insure maximum removal of the insoluble and the exceedingly clear filtrate being received in 800 cc. beakers. Care was taken not to disturb the precipitate throughout this and similar operations. All such end-products were discarded thus simplifying many operations and thus avoiding re-contamination.

Now experience teaches that gold precipitated with sulphur dioxide may be contaminated with palladium if present and that precipitated with oxalic acid with copper, lead, etc. It is obviously necessary to employ both methods.

The solution was heated to 80° C. and charged with SO_2 gas from a cylinder. Complete precipitation was insured by the careful addition of NH_4OH (1-1) until the pale yellow color disappeared, taking *every* care to avoid making the solution ammoniacal and adding only enough to neutralize the hydrochloric acid present or liberated. The gold sponge was allowed to stand overnight and the solution decanted through close textured papers. Washing of the sponge was by decantation with hot water, then heating on the water-bath for 4 hours with conc. HCl and finally finishing with hot water. Gold collected in the filter papers was discarded.

The gold sponge remaining in the beakers was again dissolved, and the entire treatment repeated, as described, 8 separate times to insure removal of silver, copper, nickel, zinc, lead, etc. Each time the reprecipitated sponge gold was treated 4 hours with hot concentrated HCl, washed free of acid with hot distilled water. It was then digested with NH_4OH and H_2O (1-1) for 12 hours and the ammonia washed out by decantation with hot H_2O. Finally, covered with hot concentrated HNO_3 and digested for 4 hour periods on the water-bath, the acid decanted, NH_4OH (1-1) again added and later on washed free with H_2O.

The sponge was now dissolved again in dilute aqua

Bausch & Lomb Quartz Spectrograph. Illustration shows connections for making and controlling the arc, special arc and spark stand used for generating arc, special motor-driven sector for integrating light from arc, quartz condensing lens arrangement between arc and instrument, and at right a projection lantern and overhead reflecting mirror for projecting a magnified image of the spectrum for detailed study.

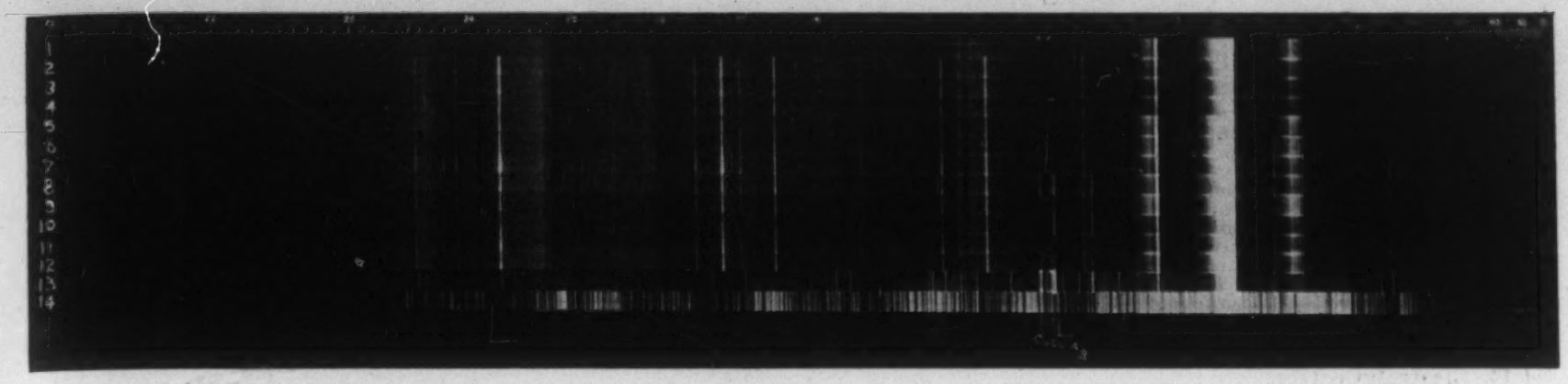


Fig. 1.

regia and evaporated with HCl (4-1) to remove HNO_3, diluted and decanted as before. This time the gold was precipitated by adding finely ground oxalic acid crystals to the warm solution in small portions. Care must be used as the reaction is violent and frothing over must be avoided. If yellow colored solutions are encountered NH_4OH is cautiously added to neutralize HCl and more oxalic acid added until the solution is colorless indicating complete precipitation of the gold. This sponge is redissolved as described and again precipitated with oxalic acid. This should insure removal of palladium.

Finally the sponge was again dissolved and reprecipitated by means of SO_2, digested with conc. HCl, washed with H_2O, and all traces of acid removed with NH_4OH until no reaction for chlorides was given. Having been drained the sponge was transferred to a clean glazed porcelain casserole and dried at 110° C.

A spectrographic examination of the gold at this stage by means of the arc showed no evidence whatever of either copper, silver, nickel, zinc or the platinum metals.

Melting of the Gold Sponge

In order to insure continuance of the high purity so far attained, the gold was melted in a small Ajax-Northrup furnace using a crucible made from a 2″ diameter specially purified graphite electrode procured from the Acheson Graphite Company. The crucible was made by boring a ¾″ hole about 5″ deep. A portion of the sponge gold was tamped into this hole and melted and then additional sponge added, etc., until all was molten. Having been melted, no flux being used, the molten metal was poured into a mold made by drilling a ½″ hole 4 inches deep into a similar graphite electrode. After cooling and removal from the mold, the pipe end was cut off. The total wastage for preparation and melting was about 30 g. or 1/6 the original weight taken.

As usually prepared for our own purposes as a proof gold, the sponge is melted in pure bone-ash cupels or on charcoal by means of a gas torch but such gold when examined spectroscopically by means of the spark shows evidence of calcium and magnesium. In the preparation of this particular batch, it appeared desirable to use graphite in order to reduce the possibility of contamination by those 2 elements and thus increase the field of use of the gold or the gold wire.

Rolling and Drawing of the Ingot

The very pure gold in ingot form, as above, was sent to Mr. Edward A. Capillon of the D. E. Makepeace Co., Attleboro, Mass. In view of the great softness of this noble metal and hence the ease with which foreign metallic particles can become imbedded in a bar in mill processing, special precautions again had to be taken to prevent contamination. All rolls and draw-dies were carefully cleaned previous to rolling or drawing the rod. After each rolling or drawing reduction of roughly 50% in cross-sectional area the gold rod was chemically cleaned in (1) a hot mixture of 50% c.p. conc. HNO_3 and H_2O, (2) a hot water rinse, (3) a hot mixture of 50% c.p. conc. HCl and H_2O, and (4) final rinse in hot water. The nitric acid was used to dissolve copper and other metals soluble in this while the hydrochloric acid removed any steel particles which may have been picked up from the rolls or dies.

Cold-rolling of fine gold offers no mechanical difficulties. The metal hardens so very slowly that it is not necessary to anneal at any stage of cold-working. The rolling of the ingot was carried out in three mills equipped with parallel grooves rolling the metal to a roughly square cross-section with rounded corners. The rolling schedule was as follows:

0.5″ diam. ingot	0.365″ sq. rod (5 grooves)
0.365″ sq. rod	0.257″ sq. rod (5 grooves)
0.257″ sq. rod	0.200″ sq. rod (6 grooves)
0.200″ sq. rod	0.130″ sq. rod (10 grooves)

Chemical cleaning as outlined above was applied after each of these reductions.

Cold-drawing of pure gold offers great difficulties because of the low tensile strength of this metal (some 20,000 lbs./in.^{2}). Inasmuch as the cross-sectional area of the wire decreases at a faster rate than the frictional resistance between metal and die surfaces the difficulties of drawing soft metals such as gold, lead and tin increase disproportionately in the smaller sizes of wire. Fine wires of such metals are best made by an extrusion process. In this case, therefore, the gold rod was rolled down as far as possible with the equipment available. The rod was drawn from 0.130″ sq. to 0.100″ round in steel dies, cleaned in acid, then drawn to finish size, .085″ diam. in Carboloy tungsten carbide dies, about 10 dies being used in all. Only very light drawing strains can be applied without fracturing the wire. In this connection, it is interesting to note that at 0.090″ diameter the maximum possible reduction in diameter with a steel die was about 0.005″ whereas with the Carboloy die it was 0.007″. This is probably due to the higher polish and freedom from scratches in the harder tungsten carbide die.

Spectrographic Analyses

The spectrograms of Fig. 1 indicate that in spite of the fact that the equipment used for making this wire processes large amounts of copper-bearing gold and silver alloys, the amount of copper picked up by the gold in drawing was extremely small. As a matter of fact, as an independent examination by means of the spark spectrograph using a Hilger spectrograph showed no evidence of copper, it is felt that the faint copper lines shown in the accompanying plate are but a measure of the copper shown on occasion in the graphite electrodes used.

This spectrographic plate made in our laboratories

by means of a Bausch & Lomb instrument has for convenience a series of comparison spectrograms made up as follows:

No. 1. Graphite Electrode as blank.
No. 2. Purified Gold—as finished wire.
No. 3. Purified Gold—scrap from above.
No. 4. Purified Gold—as ingot.
No. 5. Purified Gold—as sponge.
No. 6. Pitkin Proof Gold—old stock.
No. 7. Specially prepared Gold—other make—999.98 by assay.
No. 8. Refined Gold—A Brand—999.75+.
No. 9. Refined Gold—B Brand—999.78.
No. 10. Refined Gold—C Brand—999.50.
No. 11. Cathode Gold—D Brand—999.85.
No. 12. Refined Gold—D Brand—999.85.
No. 13. Typical Dental Alloy containing Pt, Pd, Ag, Au, Cu, Zn, etc.
No. 14. Electrolytic Iron.

The copper at A.U. 3247 is barely visible in 4, 5, and 6, but somewhat more so in 1, 2, and 3. It is to be noted that No. 1 is the graphite electrode. Copper, like calcium, may be expected in graphite. When present either or both these contaminants are not homogeneously distributed throughout the graphite. There is every reason to believe, therefore, that as desired an extraordinarily pure gold was prepared which might, for present purposes, be said to be spectroscopically pure.

Acknowledgment

The preparation of the gold sponge was carried out in the laboratories of Lucius Pitkin, Inc., by the Chief Chemist, Mr. John Jicha. The melting and casting were done by our Vice President, Mr. Sam Tour, with facilities tendered through the courtesy of Sigmund Cohn, Inc., of New York, and the wire drawn by Mr. Edward A. Capillon, Metallurgist of the D. E. Makepeace Co., who has also been kind enough to write up the description of the wire drawing operations for this paper. The spectrograms were made by our Assistant Spectroscopist, Mr. George Kuck.

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Invar, Elinvar and Related Iron-Nickel Alloys

(Continued from Page 135)

to be present in commercially produced alloys. The extent of the utility of the cobalt additions may be judged by comparing the data in Table 1 with that in Table 2. For an inflection temperature of 500°C. (932°F.), for example, the substitution of 28% cobalt for the same percentage of nickel will lower the minimum coefficient of expansion from 9.3×10^{-6} per °C. (5.2×10^{-6} per °F.) to 5.3×10^{-6} per °C. (2.9×10^{-6} per °F.) and the mean coefficient from 9.8×10^{-6} per °C. (5.5×10^{-6} per °F.) to 6.35×10^{-6} per °C. (3.5×10^{-6} per °F.).

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White Metal Bearing Alloys

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Some Properties of Pure Silicon

(Continued from Page 137)

amined with the microscope. The three photomicrographs shown in Fig. 2 were taken with a magnification of 100X. The area (a) is average grain size, (b) shows a number of twins, and (c) shows one of the fine-grained areas. The small dark particles in each view, but especially in (c), are minute blow holes which contain foreign material from the grinding operation. Still finer particles could be observed in the original specimens which may have been actual impurity constituents.

In conclusion it may be pointed out that pure silicon is one of the few pure metals which are brittle in the cast condition.